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REPORT

OF THE

UNITED STATES-BOARD

APPOINTED TO TEST

IRON, STEEL,

AND

OTHER METALS.

IN TWO VOLUMES.

VOLUME I.

WASHINGTON:
GOVERNMENT PRINTING OFFICE.
1881.

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Hon. Geo. F. Hoar.

IN THE SENATE OF THE UNITED STATES,
May 5, 1880.

The following resolution was agreed to by the Senate December 16, 1879, and concurred in by the House of Representatives May 5, 1880:

Resolved by the Senate, the House of Representatives concurring, That three thousand copies of the report of the Board to Test Iron, Steel, and Other Metals be printed for the use of Congress, one thousand for the use of the Senate and two thousand for the use of the House.

Attest:

JNO. C. BURCH,
Secretary.

REPORT.

UNITED STATES BOARD FOR TESTING IRON, STEEL, &C.,
Watertown Arsenal, Mass., June 8, 1878.

SIR: I have the honor to report that the Board for Testing Iron, Steel, and Other Metals, appointed by the President of the United States in his order dated Executive Mansion, March 25, 1875, in accordance with the provisions of the fourth section of the act entitled "An act making appropriations for sundry civil expenses of the government for the fiscal year ending June 30, 1876, and for other purposes," approved March 3, 1875, met at Watertown arsenal, Mass., on the 15th of April, 1875.

There were present Lieut. Col. T. T. S. Laidley, Ordnance Department, U. S. A., president of the Board; Commander L. A. Beardslee, U. S. N.; Lieut. Col. Q. A. Gillmore, Engineer Department U. S. A.; David Smith, chief engineer U. S. N.; W. Sooy Smith, civil engineer; A. L. Holley, civil engineer; R. H. Thurston, civil engineer.

The instructions of the Board prescribed their duties, which were to "determine, by actual tests, the strength and value of all kinds of iron, steel, and other metals which may be submitted to them, or by them procured, and to prepare tables which will exhibit the strength and value of said materials for construction and mechanical purposes, and to provide for the building of a suitable machine for establishing such tests, the machine to be set up and maintained at the Watertown arsenal."

The Board proceeded to organize committees which were charged with the prosecution of such work as could be carried on with the means at the command of the Board, and with such machines as could be made available for the purposes during the time that the large testing-machine should be in process of construction.

To these committees was severally referred the consideration of the following subjects:

Abrasion and wear.—To examine and report upon the abrasion and wear of railway wheels, axles, rails, and other materials under the conditions of actual use.

Armor-plate.—To make tests of armor-plate; to collect data derived from experiments already made to determine the characteristics of metal suitable for such use.

Chemical research.—To plan and conduct investigations of the mutual relations of the chemical and mechanical properties of metals.

Chains and wire ropes.—To determine the character of iron best adapted for chain cables; the best form and proportions of link, and the qualities of metal used in the manufacture of iron and steel wire rope.

Corrosion of metals.—To investigate the subject of the corrosion of metals under the conditions of actual use.

The effects of temperature.—To investigate the effects of variations of temperature upon the strength and other qualities of iron, steel, and other metals

Girders and columns.—To arrange and conduct experiments to determine the laws of resistance of beams, girders, and columns to change of form and to fracture.

Iron, malleable.—To examine and report upon the mechanical and physical properties of wrought iron.

Iron, cast.—To consider and report upon the mechanical and physical properties of cast iron.

Metallic alloys.—To assume charge of a series of experiments on the characteristics of alloys and an investigation of the laws of combination.

Orthogonal simultaneous strains.—To plan and conduct a series of experiments on simultaneous orthogonal strains, with a view to the determination of laws governing the same.

Physical phenomena.—To make a special investigation of the physical phenomena accompanying the distortion and rupture of metals.

Reheating and rerolling.—To observe and to experiment upon the effects of reheating, rerolling, or otherwise reworking; of hammering, as compared with rolling, and of annealing the metals.

Steels produced by modern processes.—To investigate the constitution and characteristics of steels made by the Bessemer, open hearth, and other modern methods.

Steels for tools.—To determine the constitution and characteristics and the special adaptations of steels used for tools.

Proposals were invited for the construction of a testing-machine capable of exerting and measuring a strain of tension and compression of 800,000 pounds, and on the 19th of June, 1875, a contract was made with Mr. A. H. Emery, of New York City, for the construction of such a machine, to be completed in five months from the date of signing.

Owing to unexpected difficulties, common in the development of new and untried constructions, the contractor, without any fault or negligence on his part, so far as known to the Board, has failed as yet to bring his work to a satisfactory conclusion. The foundation of the machine has been laid in a manner to meet the heavy strain that will be brought upon it at the moment of rupture of large specimens; the track has been laid, and portions of the straining-apparatus and the pump have been erected at this arsenal. The contractor found in the course of numerous tests with the gauges for the machine that he could improve them, and they have all been reconstructed and thoroughly tested, and are now highly satisfactory in their construction and action. In testing the large scale several changes were found desirable, and a very considerable portion has been made over, embracing all the desired changes, and it is now being thoroughly tested preparatory to its final rating and adjustment. These alterations and tests have consumed much more time than was expected, but the contractor now hopes to have the tests completed and the whole machine in operation during the present month.

The Board has established in one of the buildings at this arsenal a chemical laboratory, which has been fitted up and furnished under the direction of Mr. Andrew A. Blair, of Saint Louis, who has been appointed chemist to the Board. It is complete in all its appointments, and provided with every convenience for facilitating the kind of work for which it was intended. Mr. Blair has analyzed 213 steels and irons and 249 alloys, the physical properties of which have been tested. The Board has every reason to congratulate itself on securing the services of so able a chemist. Mr. Blair has worked, I can say, with untiring industry and thorough conscientiousness, equaled only by his eminent skill.

The confidence to be placed in the results obtained by analysis depends much upon the methods which have been employed. If the method be defective, no manipulation, however skillful, can produce reliable results. In order that it may be seen what methods have been used, and their accuracy thoroughly tested, if desired, Mr. Blair has

given in his report, which is forwarded herewith, a description of all the methods used by him, some of which are old and well known, and others are of his own devising. Some of the latter which have become known have received favorable commendation, and it is believed that his report will be a valuable contribution to this branch of scientific investigation. In the selection of methods he has chosen those which insure accurate results rather than economy of labor.

The committee on metallic alloys has made a thorough investigation of the strength and other properties of bronzes, brasses, and the triple alloys of copper, tin, and zinc in castings of small size. The experiments were made, under the direction of Prof. R. H. Thurston, chairman, in the mechanical laboratory of the Stevens Institute of Technology, the Board paying the customary charges for the use of machines, tools, &c.

The metals were first weighed out carefully in given proportions, and cast in bars 28 inches long and 1 inch square in cross-section. They were cast, some in sand and others in an iron mold, in the ordinary way, without the use of special fluxes, and the temperatures taken at the time of casting. Samples of each alloy were broken by tension and by transverse strain, and other samples were subjected to compression and torsion. Their strength, elasticity, ductility, resilience, and homogeneity were recorded and graphically represented, specimens of each were analyzed by the chemist, and a comparison was thus instituted between the proportions weighed out and the composition found to exist in the bar, exhibiting the loss of the several constituents produced by melting and casting.

The report on bronzes has been completed, and is herewith transmitted; that on brasses and triple alloys is well advanced toward completion; it is not yet in a condition to be forwarded, but will be in the course of a short time.

The result of all of this work, so far as the tensile strength of all the possible alloys that can be made from any two or all three of these metals, is shown at a glance by a model ingeniously devised by Professor Thurston, a map of which is herewith transmitted, marked "Plate I."

An equilateral triangle of 10 inches length of side divided into one hundred equal parts was taken. At each angle was erected a vertical ordinate, representing in length the tensile strength of copper, tin, and zinc, respectively, on a scale of 25,000 pounds per square inch for each inch of length of ordinate; the ordinates were pieces of brass wire fastened securely to the plate At a distance of 1 inch from the angle representing copper, an ordinate was erected representing the tensile strength of the gun-bronze composed of 90 parts of copper and 10 of tin. In the same way ordinates were erected at other points, representing the other alloys according to their several proportions, and by their respective lengths of ordinate the strength of the particular alloy designated. The same was done with the various brasses that were tested, and also with the triple alloys of copper, tin, and zinc, 106 points being thus determined. A triangular box was formed, in which plaster of Paris was poured until it covered the tops of all the ordinates. The plaster was then removed until the top points of the different ordinates were just visible and the model was complete.

By intersecting this model by horizontal planes one-tenth of an inch apart we obtain the contour-lines shown in the map, which gives the tensile strength of all the different alloys to within 2,500 pounds of their true strength.

Appended to the report is a paper collated by Professor Thurston, embodying the most important facts previously determined in regard to the copper-tin alloys, and also graphical records of their conductivity for heat and electricity, their specific gravity, and other properties, as determined by previous experimenters. This paper also contains the complete bibliography of the subject of bronzes, now for the first time collected and put into a compact form.

The committees on chain cables, malleable iron, and rerolling iron have made an extended series of experiments at the Washington navy-yard, under the immediate direction of Commander L. A. Beardslee, chairman, who has performed his part with conspicuous intelligence and fidelity, and have embodied the results in a comprehensive and most valuable report forwarded herewith. Wrought iron, for chains, of many different brands—most of which of well known and high repute—varying in size from 1 inch to 2 inches in diameter, was tested, both in the shape of bars and short chains. More than two thousand tests were made of the tensile strength, and the results have been carefully tabulated, giving the elastic limit, elongation, and reduction of area of each specimen.

In these experiments it was sought to determine by tests of bar-iron what kind of iron was best adapted to make chain cable, what were the best form and proportion of link, and to ascertain, if possible, the relation between the chemical composition and physical properties of the specimens. As chains are often subjected to great and sudden strains, the tests of the iron were made by impact as well as by tension slowly applied.

By the kindness of the Navy Department, the facilities of the Washington navy-yard, which included the use of two testing-machines, one of a capacity of 300,000 pounds, were placed at the disposal of the committee, and the record of an extensive series of experiments made for a similar purpose was thrown open to them.

The report contains in detail the results of numerous experiments, which establish conclusively points about which difference of opinion has heretofore existed, confirms the correctness of certain positions, and in some cases directly contradicts what has been regarded by eminent authorities as well-established facts. It shows that the most important characteristic which a good chain-cable iron should possess is the property of making uniformly a perfect weld. The presence of any impurity in sufficient quantity to affect it injuriously in this particular must prove fatal to its claim for favorable consideration. It proves that the proper place for the weld is at the end, and not on the side, and that in all cases where studded links are not absolutely required they should be carefully avoided, for the reason that the studs are found, contrary to the usually received opinion, to diminish materially the strength of the chain.

The practice which obtains in most of the prominent chain-factories in this country, of proving the finished chain by the tension prescribed by the standard proof-table of the British Admiralty, is shown to be faulty and attended by consequences in the highest degree dangerous. It is rendered more than probable that the use of this table in the proof of chain cables has been the direct cause of the loss of many anchors, and, possibly, vessels. The strains prescribed are too great for all sizes of chains, and notably so for those of large chains. The committee has accordingly constructed and inserted in their report a proof-table which is adapted to cables of various sizes made of American iron, and by the use of this table instead of that previously used, much risk of positive injury to cables by excessive proof will be removed.

This table constructed as it has been from so wide a field of practical tests, will, it is believed, be found to be of great use to this branch of industry, and will soon become the recognized standard for proving all

American chains. This report shows that in the search for a proper chain-iron a very high tensile strength indicates an unfitness for this purpose, for the reason that this strength is usually caused by the presence of carbon, copper, or other substance in quantities which would injure its welding properties or render it liable to break under sudden strains. Many minor points of interest in these investigations have been carefully noted, and will be found discussed in the body of the report: such as the proper shape of the piece to be tested, the effect of removing the outer skin of the iron upon its strength, the elevation of the elastic limit, the reduction of area, which is produced both by sudden and steady strains, the appearance of the fracture as produced by shock or steady pull, &c.

It has been known that the strength of iron bars is not in direct proportion to the size, but it has been reserved for Commander Beardslee to propose a means by which bars of different sizes may be made to have the same proportional strength. He has proved by actual experiment that a uniform reduction in rolling, from the size of the pile to the finished bar, will produce a uniform strength of bar: but the additional cost of manufacture in large bars will be very considerable.

This report shows clearly in what direction we must work for the improvement of manufacture of chain cables: First, the means for dispensing with the studded link, and, second, an improved method of welding, in a non-oxidizing flame where the intensity of the heat can be easily regulated.

All the different irons tested in these experiments were carefully analyzed by the chemist of the Board; and an able paper by Mr. Holley, discussing the connection between the chemical composition of the iron and its physical properties, accompanies the report, and gives additional value and completeness to it.

The committee on steel for tools has made a series of experiments at the Washington navy-yard, with a view of determining by actual tests the constitution and characteristic qualities of steels for various purposes for which they are required as tools and their special adaptation for the work of turning, planing, boring, slotting, and chipping. The experiments were made under the immediate direction of Chief Engineer David Smith, U. S. N., chairman, who has carefully noted everything that could possibly be of interest in the working of the tool. The Navy Department gave the use of the necessary machines and facilities for doing the work free of charge.

Seventeen different lots of the best steels to be had were procured in open market, embracing 70 separate bars, and representing the production of 14 different manufacturers, 11 American and 3 English—the most celebrated in each country. Each of the several tests with the tools of the various steels was conducted in precisely the same manner in every detail, and the results obtained and tabulated are comparable with each other in every particular; it is believed they represent the true practical value of each of the steels for the special purpose for which the tool was used. A full and complete record of the experiments made with each steel has been kept; and all important facts observed in regard to its character and texture, its treatment in the making and use of the tool, and everything pertaining to the work of testing it that was thought could in any way affect the results were carefully noted. Samples of the same steels, embracing 408 specimens, have been tested by tension, torsion, and compression, and the specific gravity of each bar carefully determined.

All of the necessary computations required in connection with the foregoing tests have been completed and the results tabulated. Thirty different bars have been analyzed by the chemist of the Board, and all that now remains to be done is to discuss and compare the physical properties with the chemical composition of the steels. This the chairman has not had the time and opportunity to do.

In order that he might complete this work application was made to the Navy Department that he might be relieved for the time being from other duty. The request was not granted, and no other member of the Board was available who was conversant with the subject to take up the report and finish it.

The report of this committee when it shall have been completed will contain a large amount of data, and conclusions therefrom, which it is believed will enable the maker and user of tool-steels to distinguish readily between good and indifferent steels by comparing the physical properties and chemical constitution of any given steel, and to determine beforehand whether a steel will be well adapted or not for any special purpose by such a comparison. It also exhibits in a highly satisfactory manner the position which American steels take when compared with the highest priced and most celebrated tool-steels of European manufacture.

The committee on girders and columns have made some experiments on the strength of materials of different forms and proportions used in the construction of bridges. Owing to the great expense attending such experiments the tests have been confined principally to material gratuitously furnished by a manufacturer of rolled beams at Buffalo, N. Y. The results of these experiments have not been communicated to me by the chairman of the committee, nor have I received from him a report called for, giving the status of the work under his charge.

The committee on chemical research has undertaken a series of experiments on steels, with a view of determining, if possible, the effect of varying quantities of some of the most common elements ordinarily found in steels on their mechanical properties. In each series one element is made to vary within wide limits, while the others are kept as uniform as possible. In this way the effect of different quantities of carbon, phosphorus, silicon, sulphur, &c., is to be determined. This investigation, the importance of which has long been felt, has never been, it is believed, previously even attempted.

It is also intended to determine the effect of one impurity in modifying or neutralizing the influence of another. Considerable work has already been done in the prosecution of these experiments; 123 specimens have been prepared and tested by tension, the calculations made and tabulated, and the curves completely plotted; 190 specimens have been tested in the autographic machine, and the strain-diagrams and other results made ready for the report.

Work is now progressing on another set of 60 specimens, after which an additional series of 86 test-pieces is to be commenced, when a careful study and comparison of the mechanical and physical properties with the chemical analyses will show the influence of the variation of composition and the effect of one element upon another.

An examination has been made of certain English rifle-barrel steel received from the National Armory, which had proved deficient in strength and found to contain numerous fine seams, unfitting it for this use. An analysis showed that it contained an excessive amount of sulphur and phosphorus, .104 per cent. of the former and .166 per cent. of the latter.

The statement of funds received and expended since the organization of the Board is given in Appendix 2. The disbursements have been made in accordance with the rules and regulations of the Ordnance Department, and the vouchers, giving the cost of the articles purchased and the details of the transactions, with the receipts for the money paid, have been forwarded to the Ordnance Office.

A provision was inserted in the act of Congress authorizing the Board, limiting the amount which should be used for the expenses of the Board to $15,000. Of this sum only $2,248.79 have been expended for this purpose. The balance on hand on the 1st of June amounts to $12,193.92; $6,299.48 remains to be paid for the machine, and $3,700.52 for its transportation and erection. The balance is due on contracts made for material and services not yet rendered.

It was not to be expected that the Board should do any very large amount of work before the completion of its large machine. It is, however, believed, as has been said by high authority, that what has been accomplished is worth more to the government and the private industries of the country than the whole of the appropriation, including that paid for the machine.

In a few weeks more the Board will have a machine more accurate and better adapted for doing work of all kinds, light and heavy, than any other machine at present known, and be in condition to prosecute its work to advantage.

The Board deferred making its report until it could announce the completion of all work commenced and the erection of its machine, and regrets that circumstances over which it could exercise no control prevent it from reporting this at the present time.

Congress at its last session declared that the Board should cease to exist when the money then appropriated should have been expended. In view of the results which have been thus far obtained, under circumstances unfavorable to the accomplishment of such a work, and of the fact that the Board will soon be provided with the best of facilities for testing metals, it may well be suggested whether a wise policy, a just appreciation of the advantages to inure to the various industries by such action, will not prompt the grant of a further appropriation to carry on the work for which the Board was appointed. This work has enlisted the active sympathies of scientific men of all classes, and metal-manufacturers of the country, the last of whom have not confined their interest to mere expressions of approval, but have supplemented them with donations of money to the amount of $1,475, for the completion of some work on steels, which was commenced but could not be finished on account of the failure of the appropriation by Congress.

From what the undersigned knows of the wants of officers having charge of government constructions, the want of definite information on the part of civil engineers, architects, and mechanical engineers throughout the country, and their utter inability to obtain correct data on which to base their calculations, for the want of which large sums have annually to be expended in order that the errors made may be on the side of safety, there is no purpose for which an appropriation could be granted which would yield so large and immediate a return in the way of money absolutely saved as a further grant for the work of this Board, and in the correctness of this opinion he is confident that he will be supported by the whole body of scientific men and manufacturers of metals of superior quality throughout the land.

I have the honor to be, very respectfully, your obedient servant,

T. T. S. LAIDLEY,
Colonel of Ordnance, President of the Board.

To the PRESIDENT OF THE UNITED STATES.

Statement of disbursements under appropriation, "Test of Iron and Steel," to June 1, 1878.

Disbursements.	Tests of iron and steel.		
	1875.	1876.	1877.
For advertising (contract for testing-machine)	$172 50	$99 75	....
amount paid on contract for testing-machine	25, 200 52	....	....
stationery and printing	....	500 41	$104 85
instruments (calipers, stamps, &c.)	....	129 50	....
fitting up chemical laboratory	51 88	1, 912 37	47 10
chemicals, apparatus, &c	....	2, 604 89	692 75
care of chemical laboratory	....	151 13	125 63
coal for gas for use at chemical laboratory	....	254 50	480 29
coal and wood for heating laboratory, turning specimens, &c.	....	351 71	111 35
labor for cutting samples, turning specimens, &c.	....	983 20	18 38
fitting up building for testing-machine	....	1, 417 01	531 99
foundation for testing-machine and setting up accumulator	....	4, 083 77	430 91
traveling crane and trestles	....	2, 746 29	234 94
coal and oil for operating testing-machine	....	....	227 80
material for tests	....	3 97	1, 091 27
freight and expenses on samples of iron, steel for tests	....	26 67	20 65
freight on parts of testing-machine received	....	53 09	310 54
boxes for parts of testing-machine received	....	152 39	....
traveling expenses of members	346 62	1, 146 63	755 54
postage (secretary and members)	....	117 90	40 99
secretary, from March 25, 1875, to June 30, 1877	300 00	1, 316 66	1, 100 00
chemist, from July 1, 1875, to April 29, 1878	....	5, 550 00	2, 108 50
committee on abrasion and wear	....	83 50	....
committee on chemical research and steels by modern processes.	....	378 44	859 25
committee on chain cables, and reheating iron	....	1, 394 93	1, 638 86
committee on effects of temperature	....	938 03	25 22
committee on beams, girders, and columns	....	3, 042 06	1, 470 98
committee on cast iron	....	29 10	....
committee on metallic alloys	....	10, 516 84	1, 074 75
committee on steels for tools	....	2, 644 17	....
Total	26, 071 52	42, 628 41	13, 502 54

TESTS OF IRON AND STEEL, 1875.

To appropriations		$75,000 00
By amount disbursed	$26,071 52	
By amount transferred to appropriation, "tests of iron and steel, 1876"	42,629 00	
		68,700 52
Balance on hand (due on contract for testing-machine)		6,299 48

TESTS OF IRON AND STEEL, 1876.

To amount transferred from appropriation, "tests of iron and steel, 1875"		42,629 00
By amount disbursed	42,628 41	
By amount deposited to the credit of the Treasurer of the United States	59	
		42,629 00

TESTS OF IRON AND STEEL, 1877.

To appropriation		19,396 98
By amount disbursed	13,502 54	
		13,502 54
Balance on hand		5,894 44

T. T. S. LAIDLEY,
Colonel of Ordnance, President of the Board.

REPORT

OF

THE COMMITTEES

ON

CHAIN-CABLES, MALLEABLE IRON,

REHEATING AND REROLLING WROUGHT IRON,

GIVING

THE RESULTS OF EXPERIMENTS ON THE STRENGTH OF WROUGHT
IRON IN BARS AND IN CHAINS; THE EFFECT OF DIFFERENT
DEGREES OF REDUCTION IN ROLLING, OF REHEATING,
REROLLING AND HAMMERING; AND

A COMPARISON OF

CHEMICAL CAUSES WITH PHYSICAL RESULTS,

PROVING STRAINS FOR CHAIN-CABLES,

THE CORRECT FORM FOR TEST-PIECES,

AND

MISCELLANEOUS INVESTIGATIONS INTO THE PHYSICAL
PROPERTIES OF ROLLED WROUGHT IRON.

WASHINGTON:
GOVERNMENT PRINTING OFFICE.
1878.

PREFACE.

The United States Board, appointed to test American iron, steel, and other metals, assigned to three committees, designated as D, H, and M, the following subjects upon which to make investigations and report:

To Committee D ("On chain and wire ropes") the determination of the character of iron best adapted for chain cables, the best form and proportions of link, and the qualities of metal used in the manufacture of iron and steel wire rope.

To Committee H ("On iron malleable") the examination of the mechanical and physical properties of wrought-iron.

To Committee M ("On reheating and rerolling") the examination of the effects of reheating and rerolling, or otherwise reworking, of hammering as compared with rolling, and of annealing the metal.

The three committees being composed to a great extent of the same persons, all having the same chairman, and the fields of research in many respects coinciding, it was considered advisable, in order to economize time, means, and labor, that the three should be consolidated and the results of such experiments as should be made applied to all of the subjects.

Our first care was to select from the wide field to be investigated, a leading object, and our choice fell naturally upon the subject assigned to the committee on chain cables, for while it would be quite practicable to expend all of our time and means examining into the great problem, "The mechanical and physical properties of wrought iron," or the effect upon its strength and other properties, of various methods of treating it, and while so doing, procure absolutely no information which would guide us in determining "the character of iron best adapted for chain cables," we could not, on the other hand, form any judgment of value upon this latter subject, without a range of experiments, the results of which would prove of importance in connection with the other subjects of investigation.

A secondary reason for the selection was the fact that the chairman of the committees, to whom would naturally fall the duty of superintending the research, and of arranging the obtained results, was already engaged in carrying on an investigation of this branch, in obedience to the orders of the Navy Department, and through this source a large amount of information already collected could be most profitably utilized.

A further motive was the fact that all information which we might be able to obtain as to character of iron best adapted for chain cables would prove of value not only to the manufacturers and purchasers of cables and cable iron, but not less to the manufacturers of iron bridges and other constructions, which like the cable, depend for their value upon their power of resisting to the utmost, destroying forces of various and irregular natures. A cable must be able to resist sudden strains, steady strains, vibratory strains, and corrosion, and a bridge must encounter the same during its service; therefore, it is hoped that the information we have been able to collect, the deductions we have drawn, the errors we have corrected, and the rules and tables we have established and calculated, will prove of service to a large class of our manufacturers, of whom the cablemakers are but a branch.

While thus directing our efforts primarily to this investigation, we have from time to time diverged for the purpose of examining further into certain physical phenomena which have presented themselves; and the results of these investigations are given in the papers on "Form and proportion of test pieces," "Elevation of the limit of stress," "Variation in strength accompanying variation in sectional area," &c., and to a comparison of the physical results with chemical causes.

All of the experiments whose records are in this report, excepting the analyses made by the chemist of the Board, were made at the Navy Yard, Washington, D. C., the Secretary of the Navy, the Hon. George M. Robeson, having placed at the disposition of the Board all of the facilities of said yard, which included three testing machines, forges, &c., and the Chief of the Bureau of Equipment transferred to the Board the results of a series of experiments which had been carried on by the chairman of the committees, under his direction, previous to the organization of the United States Board.

In submitting this report, we would say that the extent of our investigations has been restricted by the narrowness of our means, and the necessity which has arisen that we should submit the results of such work as we have accomplished, in order that the necessity of such work shall be made as plain as the fact that our researches have been by no means exhaustive, and that they but point the way toward a thorough re-examination of the subjects involved, which, based upon our results, would provide a valuable mass of information, to which this report would occupy the relation of a preface.

L. A. BEARDSLEE, *Commander, U. S. Navy,*
Chairman of Committee D, H, and M, Editor of Report.

PREFACE TO SECOND EDITION.

Congress having authorized the printing of a second edition of the report of the United States Board, the undersigned, to whom was entrusted the duty of arranging the matter of the report of committees D, H, and M in the first edition and the editing of the same, has availed himself of the opportunity thus presented, and having obtained the necessary authorization so to do, has, profiting by experience gained while editing the first, reduced greatly the bulk of this second edition, by elimination of many unnecessary repetitions, and has, he believes, increased the value of the work, not only as was natural by the process of condensation, but also by the insertion in a portion of the space thus gained of data which have been furnished by the Navy Department, embracing the results of experiments made in continuation of those made by the Board upon points not considered as definitely settled; also of a series of torsional tests, made upon the irons whose strength under various other tests had been given.

The matter of the report has also been rearranged, so that by division into two parts all of the tests made upon round bars are separated from those made upon chain cable.

The first part may be considered as the investigation into the mechanical and physical properties of wrought iron, the second into the character of iron best adapted for chain cable.

L. A. BEARDSLEE, *Captain, U. S. Navy,*
Editor of Report.

August 1, 1881.

PART I.

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Preliminary discussion of the nature and structure of the chain link—Forces which it is called upon to resist, sources of weakness, and character of iron best adapted for its manufacture, as manifested by tests of the material, viz: the round bar of rolled iron.

Description of testing machines and methods of using them—Explanations of and notes upon the tabulated records of tension tests upon bars of round iron, including discussions upon the elastic limit, its ratio to the tensile limit, its value as a proving strain, with tables—Discussion of value of percentage, of elongation, of reduction to tensile limit and fractured areas, &c—Investigation into the effect of varying the amount of reduction from pile to bar—Effects of under and over heating the piles—Method of producing uniform tensile strength—Tabulated record of tension tests upon 959 bars of round iron.

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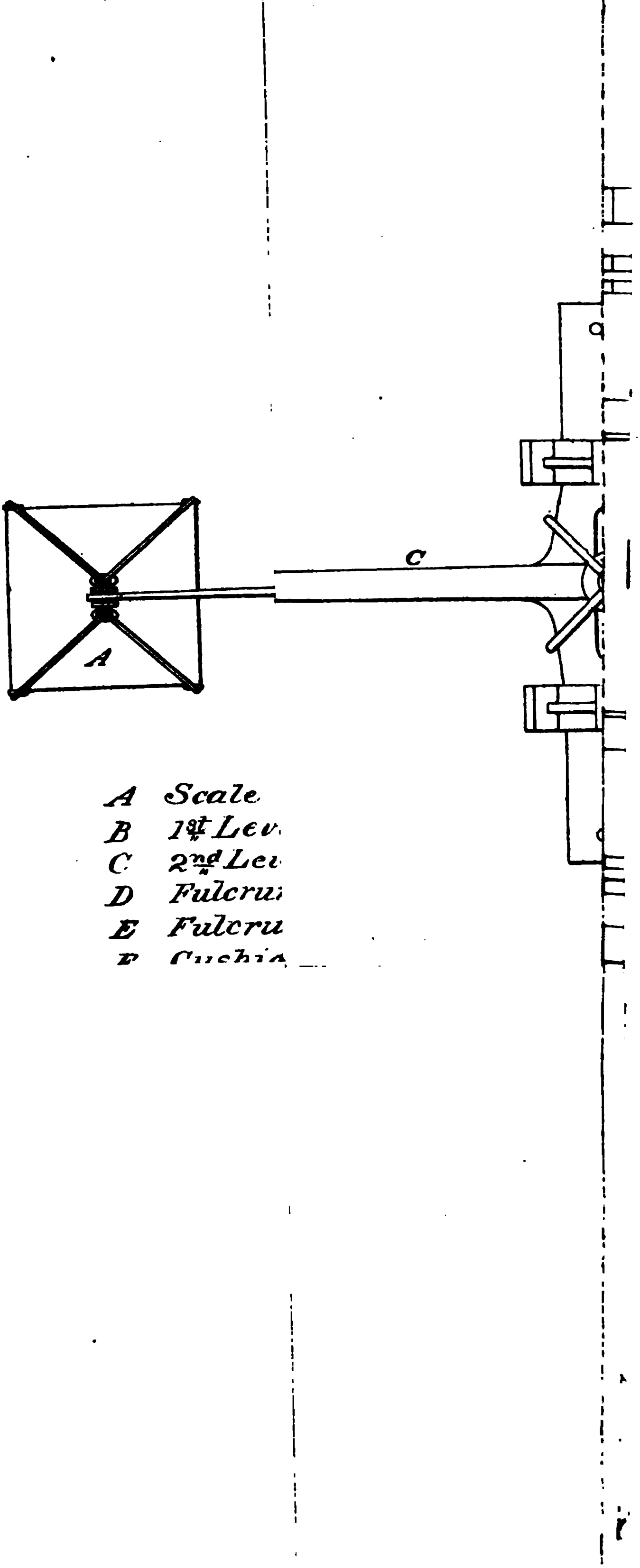
Discussion of the elevation of the limit of stress, with miscellaneous experiments to determine the effect of various strains upon form.

SECTION V.

Discussion of the necessity of tests by sudden strains, with results of such tests upon many test pieces.



A Scale
B 1st Lev
C 2nd Le
D Fulcru
E Fulcru
F Cushio

PLATE I.

TENSION TESTS.

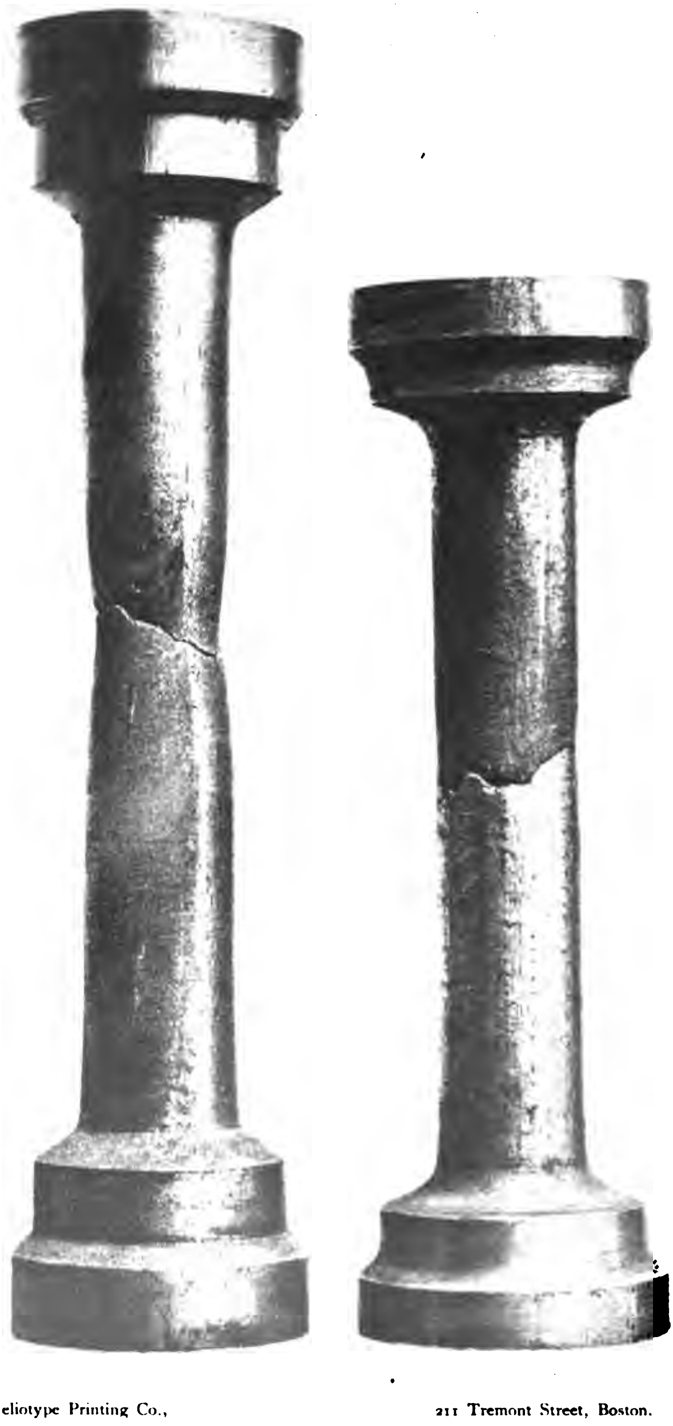


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FIG. 2. FIG. 1.

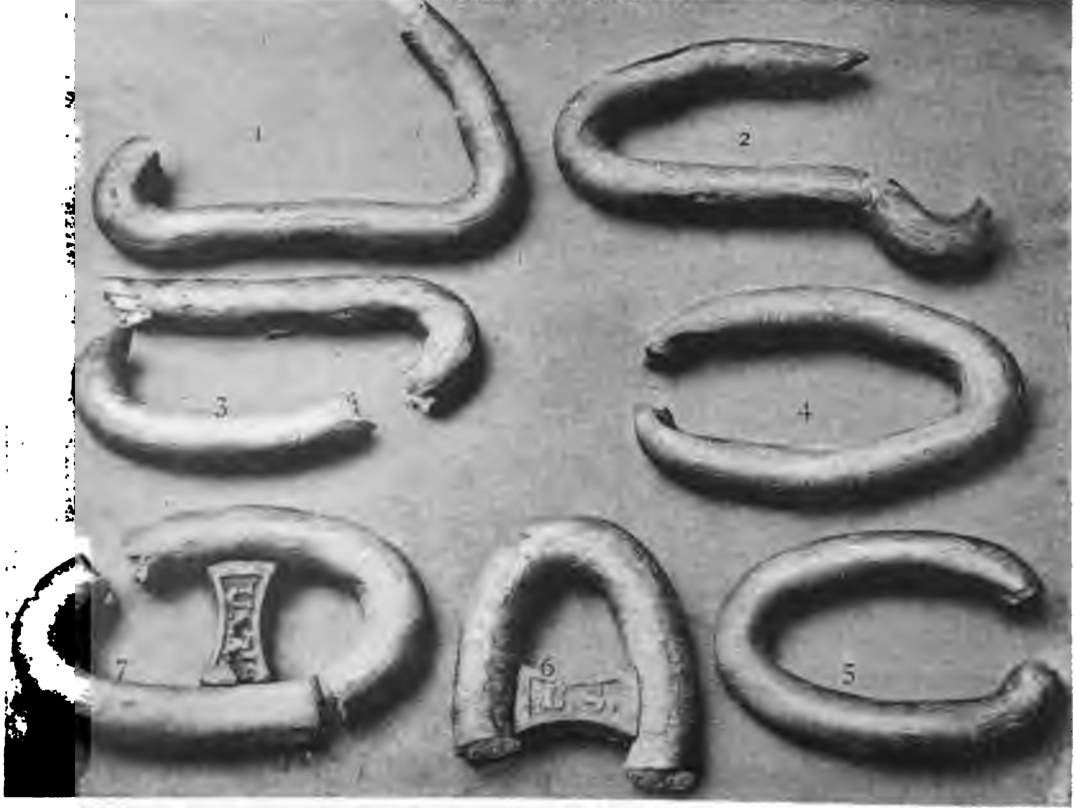
TEST PIECES BROKEN BY TENSION IN TESTING MACHINE B.

Fig. 1. Turned from a bar of contract chain iron 2 3-16 in. diameter.

" 2. " " **the same bar after it had been thoroughly reworked.**

PLATE II.

TENSION TESTS.



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TYPICAL FRACTURES OF CABLE LINKS [illegible]

PART I.

SECTION I.

PRELIMINARY DISCUSSION.

The investigations upon which we have entered have for their direct object "the determination of the character of iron best adapted for the manufacture of chain cables," indirectly the collection and classification of such data as manifest themselves during the experiments necessary for this primary investigation, and coming properly under the heading of the "mechanical and physical properties of wrought iron."

The chain cable is a result, wrought iron is the material from which it is made, and the strength and character of the cable are dependent, to a great extent, upon those of the material, and upon the methods by which said material has been produced and treated.

Our investigations begin, thus, with the material itself, which, for all practical purposes, is the *round bar*, of which the chain link is but a modification.

The made-up chain cable has undergone processes which tend to alter the inherent character of the material, some of which lower the strength of the iron, therefore it is of great importance that the character of this material should be that which in itself will tend to give, if unchanged, the greatest strength and uniformity to the links, and which is least liable to suffer deterioration during the processes by which it is transformed from bar to link.

To determine the character of iron best adapted, it is necessary to first decide upon the nature of the forces which a chain cable in service is called upon to resist, and the precedence of these forces in endangering not only the chain but the vessel which depends upon it for safety.

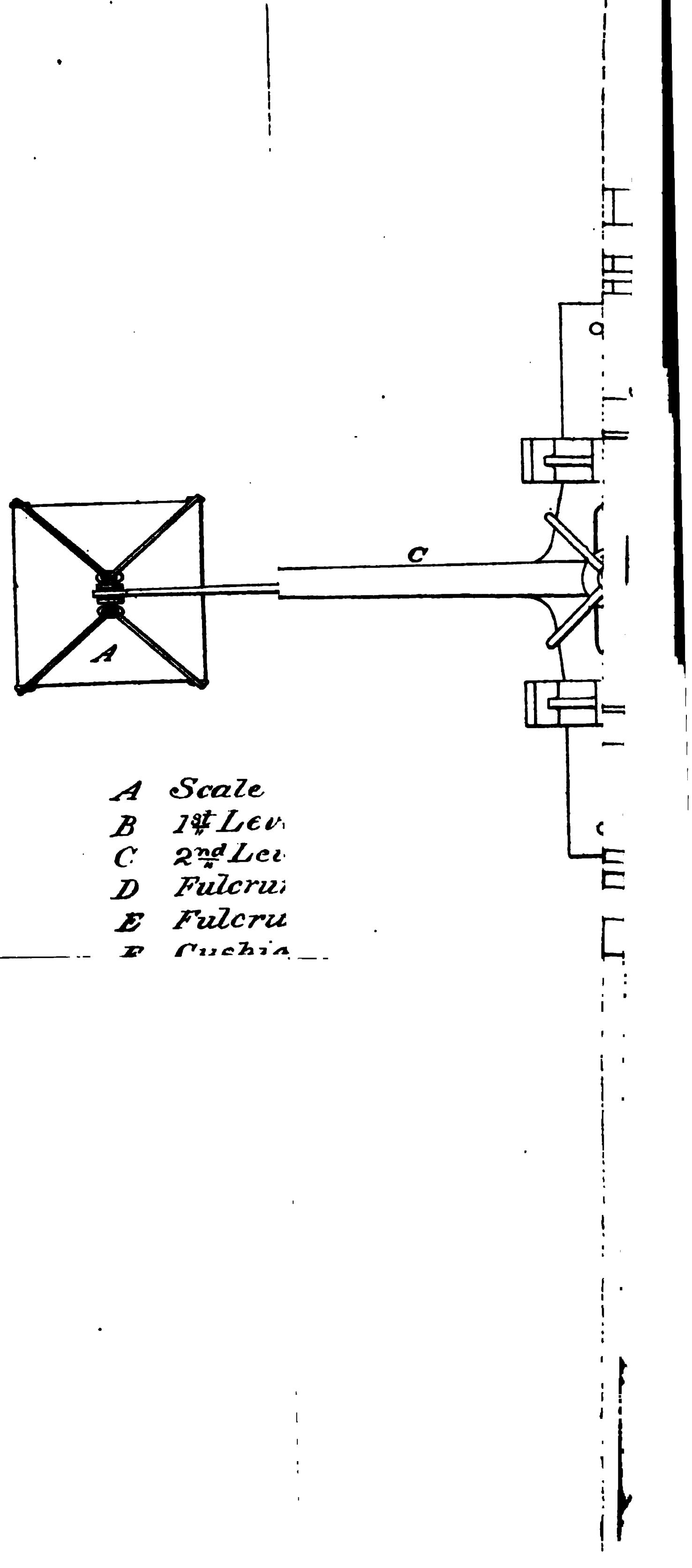
Secondly. To determine the causes which tend to weaken the chain links, and to locate the weak spots.

Thirdly. These points being determined, to fix upon the characteristics which denote that the iron manifesting them is well adapted to meet the dangerous forces, and is least liable to become unduly weakened while being bent and forged.

Cables in service are subject to the destroying forces of sudden strains, alternations of sudden and steady heavy strains, heavy steady strains, abrasion, and corrosion; and the danger from each takes precedence in the order given.

The *sudden strains*, which are the most dangerous, occur when, through any cause, it may become necessary to check the headway of the vessel by means of the anchor; or when, in letting go anchor in deep water, the momentum of the running-out cable is suddenly arrested by a jam in the hawse-hole, or pipe, perhaps before the anchor has reached the bottom.

The *alternations*, when through the force of a heavy squall, the already taut cable is strained suddenly by a force which cannot be calculated or guarded against.



A Scale
B 1st Lev
C 2nd Le
D Fulcru
E Fulcru
F Cushio

DESCRIPTION OF TESTING-MACHINES AND OF METHOD OF USE.

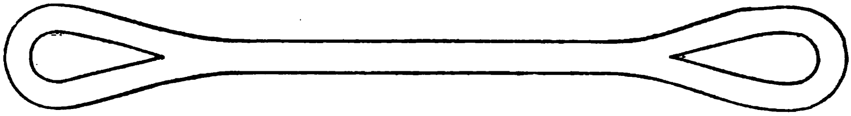
CHAIN PROVER OF WASHINGTON NAVY YARD (TESTING-MACHINE A).

This machine consists of a long trough, in which a 15-fathom section of cable can be stretched by means of a hydraulic pump, to which it is connected at one end, while the other end is made fast to a holder, which, in turn, connects with a system of levers, by which the stress is weighed by means of weights placed upon a platform at the extremity of the long lever. (See cut.)

The machine was thoroughly overhauled, repaired, and adjusted under the supervision of a Chief Engineer of the Navy previous to the use of it by the Board. The pump is worked by steam, and a gong, with wire reaching from the engine to the weighing end, facilitates instantaneous communication.

The capacity of the machine is 300,000 pounds, and the levers are so adjusted that a weight of 1 pound upon the platform balances 200 pounds of stress.

The pieces to be tested were sections of the bar at least eight times the diameter in length, and originally fitted with loops of larger-sized iron, welded to the ends, thus:



Subsequently heads were substituted for loops. Near to each end of the cylindrical portion of the bar, small punch-marks were made for the purpose of measurement; the distance between these was carefully measured, and the diameter of the bar carefully calipered; this latter process often revealed that there was between the *actual* and *nominal* diameter of the bar considerable difference.

The bar was fastened to the holders, a pair of large dividers adjusted to the punch-marks, and the stress slowly applied; at the instant the elongation was sufficient to draw one punch-mark clear of the dividers' point, the stress was weighed and recorded as *first stretch* or elastic limit.

This method was our best, but there were liabilities of error, all of which would cause the stress of "first stretch" to be recorded *too high*. At times the piece would in an instant, elongate considerably; generally such action took place in iron with high elastic limit as compared with its tensile strength. At the best the signal to stop would never be given or obeyed *before* a stretch was noticed.

Our measurers became very expert, as was the case with Mr. Tait, our assistant, who cared for the weighing, and seldom failed to keep a perfect balance, and the liability of error was reduced to a minimum.

Just before rupture there was always a period (varying with different irons) when, having reached the limit of stress, the levers would balance for a little time and then sink before the specimen parted. With this machine we were not able to trace this action very closely, but full reference is made to it in discussion of tests made by means of the dynamometer (testing-machine B), and at this point it is probable that *tensile limit* was reached.

By this machine (A) we were able to determine the tensile strength, elastic limit, ductility, &c., of round bars of any size from three inches in one-half inch, and to test to destruction chain-cable links of all sizes in to ordinary use.

Except in a few cases, which are noted, all bars tested by this machine were in the condition in which they left the rolling-mill, not having been reduced by the lathe.

RODMAN'S DYNAMOMETER (TESTING-MACHINE B).

Additional tests by tension were made upon many of the irons by means of cylindrical test-pieces turned from the bars and ruptured by the "Rodman's dynamometer," called in this paper "testing-machine B."

The results obtained by this machine agree very closely in some cases with those obtained by testing-machine A, and in others differ widely. A portion of these differences is probably due to differences in the accuracy of the two machines and methods, and others to a natural difference in the character of the metal as developed by the entire bar, and by a portion of the core and adjacent iron.

This machine holds the specimen to be tested by means of clamps, and the usual form of the test-piece is shown on Plate 1. The capacity of the machine is 100,000 pounds, and it will weigh a stress of 10 pounds with accuracy. The method of testing with it is as follows:

The test-piece being fitted to the clamps, a slight stress, sufficient to tauten everything, is brought upon it by means of a foot-screw which draws down the lower holder; the measurements are then taken, and the stress slowly applied by means of a crank, connected by gearing with a system of levers, so adjusted that a weight of 1 pound upon the platform will balance 100 pounds of stress. The stress is measured by a weight sliding on the lever until 1,000 pounds is reached, when a weight is substituted upon the platform.

The weighing-lever passes through a rectangular frame, which is 2 inches in depth of opening; the lever itself being, at the point where it passes through, 1¼ inches deep, it being thus allowed a vertical motion of ¾ of an inch. A mark across the center of the opening coinciding with one on the face of the lever indicated a balance, the stress and resistance being equalized. From the exact balance to rest there is a fall of ⅜ of an inch. The test-pieces are prepared with marks between which the length is accurately measured, and they are also accurately calipered.

In testing by this machine we have noticed that the lever rises rapidly to the stress until the elastic limit is reached, after passing which the rapidity of rise gradually lessens, until the point called *tensile limit* is nearly reached, then it rises very slowly until tensile limit is marked, when it will balance for periods varying from two to seven or eight minutes, according to the toughness of the iron. When the power of resistance is so lessened that it is not equal to the addition of stress, the lever slowly sinks and finally rests; but if during this sinking the increase of stress is stopped for a moment. on reapplying it there is a momentary responsive rise. After the fall, if the stress is continued, there is no answering rise, but the diameter reduces and the piece lengthens rapidly, and finally breaks.

The highest stress that has been reached is recorded as the tensile limit, or ultimate strength. Although we have in most cases continued the turning of the crank until rupture took place, in order that we might procure the fractured dimensions to which it was desired to reduce the strength, we, in making the investigations in regard to the elevation of the limit of stress, have frequently, after the lever had fallen to its rest, restored a balance by removing weights from the weighing-platform, and have by this process, and modifications of it, caused some peculiar phenomena to occur which have been carefully noted and tabulated. For instance, after a test-piece had withstood to the point called tensile limit, which would occur at a stress of, say, 50,000 pounds per square inch, it would, after the fall of the lever, and a slight delay for measurements, be found upon removing weights to be still resisting to nearly the extent at which the lever fell; the stress being reapplied, the lever would rise nearly, and in some cases *quite*, to the amount from which it had previously fallen, and in one or two cases to a *higher* point, and this could be repeated from twenty to thirty times; at each fall the diameter being found to be sensibly reduced and the length increased. (See pages 16 and 18.)

At the point where the lever first fell, the reduction of area which had taken place was about 50 per cent. and the elongation about 75 per cent. of that which occurred at fracture.

If, however, at the fall of the lever the weights were removed and the strain be continued, the balance would have to be preserved by continually decreasing the weights, until at last the piece which had resisted 50,000 pounds would rupture at a stress of not much over 40,000 pounds. (See pages 16 and 18.)

The results obtained by the two machines and methods are given in the following tables "Records of bars tested by tension," and cover experiments made to compare rough and turned bars; also in the investigations of the elevation of the limit of stress, and all others depending upon the action of bars under direct tension.

As the tables introduce some phenomena which have not been previously described, it may be desirable that the meanings of the results given in each of the columns should be clearly explained and apparent discrepancies accounted for.

Explanation of and notes upon the "Records of bars tested by tension."

Column headed "Diameter."—The strength per square inch of a bar as deduced from the stress at which the entire bar has been torn asunder cannot be correctly ascertained except the diameter of the bar be carefully calipered; the *nominal* size and the *exact* size seldom coincide, and at times we have found variations of four-hundredths of an inch, which variation is sufficient to produce important errors. For instance, a bar is nominally of 2″ diameter, and parts at a stress of 157,000 pounds, its tensile strength would be recorded as equal to 50,000 pounds per square inch; if however the bar was actually .03 of an inch full, and parted at the same stress, its strength per square inch would be but little over 48,500 pounds, an important difference. Therefore our diameters are those found by careful measurement.

Areas.—The "original area" is that which corresponds to the diameter of the piece before test; the "reduced area" corresponds with the least diameter after rupture; the "tensile-limit area" corresponds with the least diameter at the stress at which the lever falls; and the reductions in these are given in percentages of the original diameters. This latter can be correctly measured with ease; the fractured area cannot always, for although generally the line of fracture is at right angles to the axis of the specimen, it is not so always, and thus presenting an oval, is difficult to measure.

Length.—The length of the clear cylindrical portion between punch-marks is measured both before the stress is applied and after fracture. In testing with the machine B it is also measured at the "tensile limit."

Percentage of elongation.—This element as given in many tables is of little value, the percentage being greatly dependent upon the original length of the specimen. When this is not given the percentage is of no value.

The following experiment will make this clear: From a bar of 1¾″ iron of very uniform character three test-pieces were prepared, which were in all respects similar except in the length. The first was 75, the second 20, and the third 10 inches long. They were pulled asunder, and the first was found to have elongated 14 inches, or 18.64 per cent. of the original length; the second had elongated 4.36 inches, or 21.8 per cent.; and the third 2.22 inches, or 22.2 per cent. Our records supply many confirmatory results.

A few experiments were made for the purpose of observing closely the effect of tension upon a bar of iron in producing elongation and to decide whether the amount of elongation was equally distributed throughout the entire bar, or greatest in the vicinity of the fracture.

To make these experiments a number of bars of iron of fair quality were selected, and a number of marks made along the cylindrical portion, the marks being one inch from each other. At each of these points of division the diameter was calipered and the bars then subjected to tension. In each case the usual record was made of the stress at which the first stretch took place, and, in addition, the stress required to produce an elongation of one-fourth of an inch.

The stress was increased until the specimens were ruptured, after which they were carefully remeasured and the amount of elongation between each pair of division-marks, and the reduction in diameter at each of the points noted. In the accompanying table the results of this experiment are given; the figures preceded by an * show the location of the ruptures.

This series of experiments furnishes evidence that the greater portion of the elongation occurs in all cases in the vicinity of the fracture.

No. 4 was found to be reduced considerably at a point on the opposite end to that on which the rupture took place.

Nos. 1, 3, and 5 of the bars were tested in their natural condition.

Nos. 2, 4, and 6 were cut from the same bars as 1, 3, and 5, respectively, but were slightly reduced by the lathe before test.

Test of six test-pieces from three bars, to ascertain the proportion of elongation, &c., occurring in each inch of the piece. The odd-numbered tests, bars as rolled; even-numbered, as slightly reduced by the lathe.

Number.	Change of form at each inch of bar.								Diameter at point of fracture.		Reduced area at fracture.	Length.		Per cent. of elongation.	Stress per square inch at which—		
	Dimensions and elongation in inches and decimals.	First inch.	Second inch.	Third inch.	Fourth inch.	Fifth inch.	Sixth inch.	Seventh inch.	Original.	Reduced.		Original.	After fracture.		First stretch took place.	¼-inch stretch occurred.	Fracture took place.
											Per ct.						
1 C	Original diameter	2.05	2.01	2.01	2.01	2.01	2.02	2.04	2.01			6					
Do	Reduced diameter	2.01	1.92	*1.50	1.73	1.76	1.80	1.88		1.50	55.7						
Do	Elongation	0.20	0.47	0.67	0.32	0.32	0.21						8.19	36.5	24,053	35,701	49,770
2 C (turned from No. 1)	Original diameter	1.92	1.92	1.92	1.92	1.92	1.92	1.92	1.92			6					
Do	Reduced diameter	1.75	1.69	1.65	*1.42	1.63	1.70	1.75		1.42	54.8						
Do	Elongation	0.26	0.36	0.65	0.56	0.38	0.27						8.48	41.3	22,556	33,823	49,741
3 B	Original diameter	1.73	1.72	1.72	1.72	1.72	1.74		1.72			5					
Do	Reduced diameter	1.62	1.54	*1.32	1.50	1.62	1.63			1.32	58.9						
Do	Elongation	0.21	0.55	0.39	0.19	0.15							6.49	29.8	25,655	28,060	51,510
4 B (turned from No. 3)	Original diameter	1.61	1.61	1.61	1.61	1.61	1.61	1.61	1.61			7					
Do	Reduced diameter	1.48	*1.40	1.49	1.51	1.53	1.58	1.53		1.40	75.6						
Do	Elongation	0.30	0.18	0.12	0.15	0.15	0.12	0.18					8.20	17.1	26,810	37,670	52,103
5 bloom	Original diameter	1.29	1.25	1.23	1.23	1.24			1.25			4					
Do	Reduced diameter	1.14	*1.06	1.18	1.16	1.23				1.06	71.9						
Do	Elongation	0.45	0.15	0.13	0.13								4.86	21.5	25,050	50,352	57,288
6 bloom (turned from No. 5)	Original diameter	1.10	1.14	1.12	1.12	1.20			1.12			4					
Do	Reduced diameter	1.16	1.07	*1.00	1.02	1.15				1.00	79.7						
Do	Elongation	0.07	0.18	0.57	0.15								4.97	24.2	35,086	47,756	55,542

Elastic limit.—Our usual method of observing the stress at which this took place has been explained in measuring the first perceptible stretch.

The experiments indicate that this point, if carefully measured, furnished us with a very easy and inexpensive method by which we can obtain the *elastic limit closely enough for all practical purposes*, although, for reasons which have been given, the figures will probably prove a little above the truth.

The ratios which are borne by the elastic limit to the ultimate strength of various irons can be closely obtained by this method, as the following comparison will show:

Four test-pieces of a very homogenous iron were prepared, which were identical in form and proportions.

The two first pieces were turned from a bar of $1\frac{7}{8}''$ diameter, and the second pair from a bar of $1\frac{11}{16}''$ diameter, all of iron K.

Of each pair the elastic limit of one piece was obtained by about four hours' work, at an expense of about $4; the other one of each pair was observed at the first perceptible elongation and the stress which produced it called the elastic limit; about five minutes of time and no extra expense were required to obtain the result in this manner, the value of which is shown as follows:

Ratio of elastic limit of No. 1 to ultimate strength, by *careful test*, 53.1 per cent.

Ratio of elastic limit of No. 1 to ultimate strength, by *first stretch*' 53.4 per cent.

Ratio of elastic limit of No. 2 to ultimate strength, by *careful test*, 53.7 per cent.

Ratio of elastic limit of No. 2 to ultimate strength, by *first stretch*, 52.4 per cent.

In several other cases of careful comparison we have found close coincidence, hence have assumed this property to represent the elastic limit.

Tensile limit is the stress which represents the highest which has been withstood by the specimen, but as has been shown, it was not the amount which finally produced the rupture; this stress produced a weakening, from which had the specimen been rested, it would have recovered; by continuing it, the specimen finally parted at much less. This stress is reduced to the various areas, and in many tables is given as the "breaking strain."

Areas, original, fractured, and tensile limit.—Data in regard to the dimensions at "tensile limit" could not be obtained with accuracy by means of testing-machine A, but with B it was readily obtained, and a few remarks in regard to its use may be pertinent.

The measurements taken at the "tensile limit" introduce a new method by which the comparative values of different irons may be estimated.

Ordinarily the tenacity of iron is expressed in the strength as judged by each square inch of the sectional area of the test-piece before its form has been changed by stress.

Kirkaldy suggested, as a more just method, that the area corresponding to the diameter of the fractured surfaces should be adopted as the unit of measurement. Our experiments lead us to believe that between these extremes of original and fractured areas there is an intermediate area which can be used with profit, which is that which corresponds with the least diameter of the test-piece at the stress which marks the highest point of resistance to continually increasing strains.

This point we have termed the "*tensile limit.*"

There are practical difficulties encountered in measuring accurately the diameter of the fractured surfaces. Vernier calipers have tangible edges, which can be brought in close contact with the smooth parallel sides of the unstrained test-piece, and an error of one-thousandth part of an inch is not liable to take place, but after the test-piece has been pulled asunder there is a practical difficulty in joining perfectly the two fractured surfaces, and frequently the line of fracture is not at right angles with the axis of the cylinder; this necessitates two measurements, one of the greatest and one of the least diameter, and an interpolation, and in making these measurements there are chances of error even if the line of fracture is at right angles, which are increased when it is not. Between the edges of the calipers and the surface of the metal, if the line of the taper toward the fracture should be on both sides abrupt, as frequently occurs in testing steel and irons containing much carbon, and the reduction should be considerable, there would arise a possibility that in the attempt to measure correctly the diameter of the fractured faces in the ordinary manner, viz., by pressing the two fractured surfaces together by screw power and then calipering the line of least diameter, we would leave between the edges of the calipers and the iron a little triangular space to which we would give credit as iron in estimating the strength; in other words, without the utmost care there would be risk of *over* measurement, and of recording the fractured diameter at a little too high a figure.

If this little space on each side were but two-thousandths of an inch in depth there would be an error in measurement of *four*-thousandths, and this would produce a serious error in tabulating the results.

For instance, take at random from our records an example. Of iron F, 1¼″ diameter, the test-piece was, before fracture, .564 of an inch in diameter; it broke at 12,700 pounds stress; reduced to the square inch, this gives 50,840 pounds. The diameter is recorded as having reduced to .415 of an inch. Assume that the error of four-thousandths has been made and that the actual diameter was .411 of an inch, in that case its actual strength per square inch of fractured area was 95,704 pounds, while we have recorded it as 93,865 pounds, an error of over eighteen hundred pounds. Such an error is possible, and without great care, probable; but it could not be made in measuring the diameter of the as yet *unbroken* piece without gross carelessness, the taper being long and gradual; and an error of a thousandth of an inch seldom is made. If in measuring the original area an error of four thousandths had been made there would have been an error of but 722 pounds in the tabulated strength, the error in measurment of one-thousandth of an inch, which is possible, making an error of 184 pounds in the result. Thus the tensile strength per square inch of original area is more liable to be free from errors arising from inaccuracy than is that of the fractured area.

But neither of these measurements provides us with a standard by which we can judge of the relative amount of change of form that takes place with different irons at the moment when they *finally cease to resist* an increase of stress; this deficiency is supplied in the area at the tensile limit, which is that which corresponds to the diameter of the test-piece as affected by the highest stress the material is capable of resisting, and not by subsequent stress applied to a rapidly yielding metal.

Length of test-piece —Not only the resultant strength obtained by testing a piece of iron, but the value of the "percentage of elongation," as a factor by which to judge of the ductility, depend upon the length of the test-piece being known. Our experiments show that if an iron is judged by a test-piece whose length is less than four diameters, the judgment is wrong.

The following illustration shows the form of test-piece adopted, and the contrast between the action of coarse, brittle iron and that of a soft, ductile nature, under tension, as also the effect which can be produced by thorough reworking. The first is a specimen turned from contract chain-iron which broke at a stress of 48,000 pounds per square inch, with but little change of form; the second, whose original dimensions were the same, is from the same material reworked, and was broken at 51,000 pounds per square inch.

ACTUAL STRENGTH, AND STRENGTH AND ELASTIC LIMIT PER SQUARE INCH, OF 959 BARS OF ROUND IRON, AS OBTAINED WHERE NOT OTHERWISE SPECIFIED BY TESTING-MACHINE A.

In the following table the stresses by tension required to rupture many of the bars we have tested are arranged in their relative order, the greatest stress required being given precedence upon each size.

In the columns where the stress is reduced to the square inch, the area corresponding to the actual diameter of the bars has been used. This gives a more correct estimate of the relative order of tenacity than the first column, in which bars frequently gain or lose in precedence on account of excess or lack of material, some being rolled "full" and others "scant."

This is shown in regard to the sizes above $1\frac{15}{16}$, upon which inaccuracies in rolling occur most frequently, the breaking strain per square inch being given, and from it the entire strength which the bar would have had if it had been rolled true is also calculated for contrast.

In the column "Standard for size," the strength which we have found best adapted for chain-cable iron is placed for comparison.

The stress at elastic limit as given is not from perfectly accurate data; it is simply the amount of stress which produced the first perceptible change of form, divided by the bar's area.

Our method is necessarily coarse, and it is probable that in most cases we have recorded too high results. The determination with exactness of the elastic limit is difficult and expensive. The process of procuring it by the "first stretch" is easy and inexpensive, and the results obtained are generally correct enough for practical purposes, especially when the fact is taken into consideration that a slight difference in the heating of the piles may produce a difference of several thousand pounds per square inch in the limit of elasticity of two bars of the same lot and of the same diameter. With testing-machine A we could observe a stretch of from .01 to .03 of an inch; with B, we could observe that of .002. But even with B the results are at times inaccurate. Certain irons with low tenacity, but high elastic limit, will remain apparently unchanged, then in an instant give way, and be found to have stretched four or five thousandths of an inch. On pages 32 and 33 a series of comparisons is given by which it can be seen that, with due care in observing, the elastic limit as observed by first stretch is quite accurate enough for all practical purposes. These abstracts from the data obtained by tension upon bars are introduced here, as they furnish us with a portion of our working data used in the calculation of the proof-table. The detailed history of the tests is given in the tables of record of bars tested by tension.

The table on page 31, showing the ratios which we find to exist between the elastic limit and ultimate strength of various bars, has results which have furnished us with a maximum ratio of stress which can be considered safe to apply to a cable for proof.

Strength per original area, per square inch, and elastic limit per square inch of 959 round bars.

Size of bar.	Name of iron.	Number of tests.	Strength.		Elastic limit per square inch.	Standard for size.
			Original area.	Per square inch.		
In.			*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*
¼	F	1	2, 920	59, 885	....	
⅜	F	4	5, 886	54, 090	40, 980	
½	C	6	12, 311	62, 700	....	
	C	7	11, 699	59, 000	....	
	C	8	11, 388	57, 700	....	
	C	11	10, 881	55. 400	....	
	F	1	10, 359	52, 275	39, 126	
⅝	F	11	16, 977	55, 450	....	
	F	4	15, 928	52, 050	....	
	F	11	17, 644	57, 600	....	
¾	F	4	22, 746	51, 546	35, 933	
⅞	F	4	30, 850	50, 630	33, 931	
1	K	13	48, 480	61, 727	....	43, 665
	D	1	48, 000	61, 115	33, 486	
	O	1	46, 000	57, 363	37, 415	
	Fx 1	5	45, 040	55, 768	34, 729	
	P	2	44, 500	57, 807	39, 230	
	A	3	44, 126	54, 690	34, 881	
	Fx 2	3	44, 450	56, 790	36, 885	
	Fx 3	2	42, 350	53, 915	36, 336	
	F	2	41, 600	51, 921	31, 300	
	D	3	41, 547	52, 900	....	
	F	5	40, 660	52, 819	32, 267	
	F	4	40, 309	51, 409	34, 600	
1⅛	K	3	60, 096	60, 458	37, 344	54, 261
	D	1	58, 700	59, 582	33, 597	
	C	2	57, 125	57, 470	31, 900	
	Fx 1	5	57, 620	50, 434	34, 682	
	P	2	56, 500	57, 498	41, 311	
	N	2	56, 200	56, 143	32, 267	
	Fx 2	3	55, 100	55, 927	37, 250	
	E	1	55, 142	53, 097	33, 549	
	Fx 3	2	54, 800	54, 644	34, 695	
	D	2	54, 360	54, 687	28, 166	
	A	3	53, 997	53, 900	26, 787	
	F	3	53, 050	53. 850	33, 457	
	O	1	50, 400	53. 035	32, 410	
	F	2	50, 300	50, 149	35, 493	
	F	5	49, 660	52, 267	32, 019	
1¼	K	2	72, 960	59, 461	36, 501	65, 914
	P	2	73, 200	56, 876	30, 868	
	C	1	71, 040	57, 897	32, 469	
	D	2	72, 300	57, 977	31, 996	
	P	2	70, 704	55, 782	35, 596	
	Px	2	70, 250	50, 334	33, 921	
	N	2	69, 300	50, 478	33, 251	
	Fx 1	5	68, 460	55, 253	34, 784	
	D	1	68, 160	55, 550	28, 166	
	E	1	67, 200	53, 893	32, 712	
	Fx 2	3	66, 600	55, 132	38, 603	
	Fx 3	2	66, 400	53, 247	32, 520	
	A	3	66, 112	53, 897	27, 643	
	M	20	65, 960	53, 752	....	
	M	20	65, 850	54, 090	....	
	F	2	64, 990	52, 970	32, 075	
	F	2	64, 700	52, 729	39, 608	
	M	20	64, 285	53, 022	....	
	F	5	62, 520	52, 620	33, 220	
	O	1	61, 400	50, 040	30, 730	
1 5/16	P	94	74, 427	54, 518	35, 898	72, 133
1⅜	M	48	86, 862	58, 926	37, 548	78, 607
	M	35	87, 496	57, 649	38, 578	
	D	1	86, 800	58, 021	32, 152	

Size of bar.	Name of iron.	Number of tests.	Strength.		Elastic limit per square inch.	Standard for size.
			Original area.	Per square inch.		
In.			*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*
1⅜	K	2	82, 248	55, 790	31, 034	
	C	1	81, 600	54, 949	31, 030	
	M	28	80, 693	54, 373	35, 820	
	N	2	81, 200	54, 277	33, 622	
	Fx 1	5	80, 360	52, 968	33, 275	
	Fx 3	2	80, 000	52, 783	34, 606	
	E	1	79, 296	52, 254	25, 930	
	A	3	78, 994	53, 557	33, 650	
	P	1	78, 624	52, 536	30, 802	
	F	5	78, 580	52, 537	34, 469	
	F	2	78, 300	52, 339	39, 103	
	M	4	78, 150	53, 016	35, 379	
	Fx 2	3	76, 333	51, 487	35, 911	
	F	2	77, 235	51, 296	31, 992	
	O	1	72, 400	50, 594	34, 940	
1 7/16	P	1	89, 300	53, 345	....	85, 339
	E	1	87, 552	53, 944	32, 542	
	G	1	86, 400	53, 238	32, 534	
	B	4	84, 862	52, 287	32, 411	
	C	1	84, 000	51, 756	32, 655	
	J	1	81, 800	50, 400	....	
1½	M	12	102, 125	57, 052	38, 417	92, 322
	K	2	101, 280	57, 317	33, 412	
	D	1	101, 200	56, 505	32. 496	
	M	25	99, 064	55, 466	34, 780	
	M	26	98, 730	55, 131	33, 771	
	P	2	98, 300	54, 159	33, 140	
	M	17	98, 047	54, 540	....	
	C	4	97, 921	55, 404	34, 770	
	E	1	97, 020	55, 415	32, 869	
	M	20	97, 665	54, 816	34, 716	
	Px	2	97, 350	54, 354	34, 617	
	M	27	97, 095	54, 005	35, 544	
	E	1	96, 384	54, 544	33, 027	
	P	1	95, 904	52, 868	29, 636	
	M	20	95, 810	53, 512	....	
	M	23	94, 809	52, 941	....	
	Fx 3	2	94, 600	52, 819	34, 840	
	Fx 1	5	94, 520	53, 491	34, 307	
	M	4	93, 500	52, 786	34, 901	
	N	2	93, 400	53, 555	34, 600	
	C	1	93, 100	52, 700	35, 880	
	H	1	92, 700	52, 462	29, 992	
	D	1	92, 160	52, 155	27, 708	
	A	2	91, 680	51, 884	28, 794	
	F	2	91, 875	51, 994	32, 054	
	O	1	91, 400	50, 919	32, 312	
	F	5	90, 925	51, 456	34. 591	
	Fx 2	3	90, 967	51, 481	34, 917	
	J	1	90, 200	51, 047	....	
	M	1	87, 100	49, 292	32, 597	
1⅝	N	2	119. 000	56, 344	35, 889	107, 040
	K	4	118, 463	57, 132	35, 026	
	M	10	119. 800	57, 402	35, 701	
	P	2	117, 500	55, 634	33, 522	
	C	4	116, 892	56, 227	33, 207	
	Px	2	115, 500	54, 689	33, 427	
	A	2	111, 984	54, 334	32, 168	
	D	1	111, 360	53, 695	30, 087	
	Fx 3	2	111, 300	53, 339	38, 540	
	T	5	110, 140	53, 537	34, 335	
	D	1	110, 500	53, 614	30, 664	
	J	1	109, 400	52, 748	....	
	E	1	109, 245	52, 075	33, 745	
	Fx 2	3	108, 800	53, 438	35, 870	
	H	1	108, 500	52, 314	29, 364	
	E	1	108, 384	51, 946	27, 695	
	O	1	108, 000	52 401	34, 012	
	F	2	107, 520	52, 163	33, 907	
	G	1	106, 200	51, 205	33, 818	

Strength per original area, per square inch, and elastic limit per square inch, &c.—Cont'd.

Size of bar.	Name of iron.	Number of tests.	Strength. Original area.	Strength. Per square inch.	Elastic limit per square inch.	Standard for size.
In.			*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*
1⅝	F	2	105,500	50,529	35,390	
	F	5	105,440	50,970	83,625	
	C	1	101,700	49,030	31,099	
1$\frac{11}{16}$	K	1	130,000	56,595	38,310	114,770
	B	1	121,150	54,181	....	
	J	1	121,000	54,114	....	
	B	8	118,273	52,895	33,145	
	E	1	116,544	52,120	35,549	
	G	1	115,800	57,789	34,160	
	C	1	111,400	49,821	33,184	
1¾	K	1	139,200	57,874	....	122,745
	Px	2	131,900	54,212	33,908	
	C	5	130,836	54,410	31,354	
	P	2	130,050	52,844	33,842	
	Fx 1	5	129,500	53,846	36,573	
	H	1	129,400	53,800	27,856	
	N	2	129,350	55,018	34,283	
	D	1	128,600	53,472	31,892	
	J	1	128,100	53,264	....	
	D	1	126,720	52,699	27,817	
	Fx 3	2	126,100	53,154	35,823	
	E	1	124,128	51,606	26,541	
	A	2	123,340	51,509	29,404	
	F	1	121,920	50,690	32,229	
	G	1	121,200	50,395	36,254	
	C	1	121,000	50,312	30,852	
	F	2	120,200	50,547	35,954	
	Fx 2	3	120,167	52,314	35,320	
	E	1	119,808	49,816	31,214	
1¾	F	5	117,740	49,738	28,907	
	O	1	116,500	50,129	32,271	
1$\frac{13}{16}$	K	1	148,800	56,577	....	130,965
	B	4	138,507	53,655	....	
	C	1	131,500	50,969	30,814	
	G	1	129,850	50,310	33,565	
	E	1	129,792	50,307	29,767	
	J	1	126,300	48,953	....	
1⅞	K	2	154,080	35,803	31,031	139,430
	C	1	150,336	54,447	32,334	
	D	1	149,000	53,100	32,074	
	N	1	148,350	54,004	33,610	
	Fx 1	5	146,780	52,875	35,641	
	Fx 3	2	146,500	53.361	35,032	
	P	2	145,200	52,505	32,312	
	E	2	142,000	50,880	27,100	
	D	1	142,080	51,459	27,810	
	Px	2	142,000	51,762	32,261	
	M	2	141,300	50,303	....	
	A	2	141,120	50,584	28,713	
	F	2	140,925	51,039	33,067	
	Fx 2	3	139,000	51,159	33,970	
	F	2	136,600	49,744	35,615	
	F	3	134,500	49,355	32,855	
	F	2	132,250	48,670	23,250	
	O	1	129,000	47,478	30,842	
1$\frac{15}{16}$	M	2	155,300	51,474	....	148,137

The errors which are liable to occur in estimating the strength of an iron by data furnished by the pulling asunder of a bar or bars of it, which have not been carefully calipered before testing, are shown in the following table, in which, in some cases, it will be observed "2″ bars" would, if so considered, be credited with strength of from 5,000 to 8,000 pounds more than bars of that diameter actually possessed, the cause being irregularity in rolling, or, in some cases, attempts to obtain high records for the iron.

Strength per original and corrected areas, per square inch, and elastic limit per square inch of 88 *bars of round iron, rolled full and scant.*

Name of iron.	Number of tests.	Nominal diameter of bar.	Actual diameter of test-piece.	Stress at rupture.	Stress reduced to nominal diameter.	Stress reduced to square inches.	Standard strength of size.	Elastic limit per square inch.	Method of test and machine used.
		″	″	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	
M	1	1$\frac{15}{16}$	1.96	156,000	152,432	51,707	148,137	....	t. m. A, rough bars.
M	1	1$\frac{15}{16}$	1.96	154,000	151,061	51,242	....	....	
K.......	1	2	2.03	194,880	189,129	60,213	157,080	31,441	
K.......	1	2	2.04	188,160	180,818	57,567	....	30,839	
Px......	2	2	2.01	167,900	166,203	52,914	....	31,198	
M	1	2	2.01	167,600	165,960	52,820	....	....	
M	1	2	2.01	156,000	154,463	49,164	....	....	
E.......	1	2	2.03	167,712	162,760	51,818	....	27,818	
P.......	2	2	2.02	165,600	162,339	51,684	....	33,104	

Strength per original and corrected areas per square inch, &c.—Continued.

Name of iron.	Number of tests.	Nominal diameter of bar.	Actual diameter of test-piece.	Stress at rupture.	Stress reduced to nominal diameter.	Stress reduced to square inches.	Standard strength of s 7c.	Elastic limit per square inch.	Method of test and machine used.
		″	″	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	
P	2	2	2.01	161,300	159,670	50,834	....	31,878	
N	1	2	2.01	165,400	163,730	52,127	....	32,461	
N	1	2	2.01	163,000	161,353	51,370	....	32,460	
Fx 1	5	2	2.00	......	163,420	52,011	....	34,702	
C*	1	2	......	160,704	....	51,1[illegible]3	....	29,335	
D*	1	2	......	160,700	....	51,146	....	28,567	
P	1	2	......	159,840	....	49,872	....	29,953	
Fx 2	2	2	1.99	155,500	157,050	50,000	....	36,184	
Fx 3	2	2	2.00	159,500	159,500	50,763	....	33,172	
A	9	2	2.00	157,588	157,588	50,171	....	28,983	
F	2	2	2.00	152,260	152,260	48,596	....	27,634	
F	2	2	2.01	151,900	150,900	47,812	....	35,864	
F	5	2	2.00	149,960	149,960	47,569	....	28,792	
O	2	2	2.00	151,640	151,640	48,249	....	31,413	
D	1	2	1.97	149,800	154,367	49,140	....	33,068	
D	1	2	1.98	142,100	144,960	46,151	....	36,050	
M	1	2 1/16	2.10	178,600	172,258	51,559	....	....	
M	1	2 1/16	2.10	171,200	165,119	49,422	....	....	
M	1	2⅛	2.13	184,600	180,282	50,481	....	....	
M	1	2⅛	2.15	180,000	181,643	51,225	....	....	
A	1	2⅛	2.12	170,784	171,625	48,382	....	30,459	
M	1	2 3/16	2.22	200,000	104,161	51,666	....	....	t. m. A, rough bar.
M	1	2 3/16	2.22	200,000	194,161	51,6[illegible]6	....	....	Do.
M	1	2¼	2.28	210,400	204,883	51,530	....	....	Do.
M	1	2¼	2.26	205,800	203,982	51,296	....	....	Do.
F	1	2¼	2.24	189,600	191,293	48,812	....	....	Do.
F	1	2¼	2.24	192,700	194,418	48,898	....	....	Do.
F	2	2¼	2.09	....	195,476	49,164	....	31,966	t. m. A, turned bar.
F	3	2¼	1.03	....	195,977	49,290	....	32,163	t. m. B, turned cylinders.
P	2	2¼	2.24	184,700	186,339	46,866	....	28,241	t. m. A, rough bar.
F	2	2½	2.50	232,400	232,400	47,844	....	29,758	Do.
F	2	2½	2.36	....	237,930	48,475	....	28,932	t. m. A, turned bar.
F	3	2½	1.00	....	232,776	47,428	....	29,041	t. m. B, turned cylinders.
F	3	2¾	1.01	....	275,889	46,446	....	26,833	Do.
F	3	3	.987	....	337,003	47,761	....	26,400	Do.
F	2	3¼	.999	....	390,019	47,014	....	24,591	Do.
F	2	3½	1.000	....	452,191	47,000	....	24,961	Do.
F	2	3¾	1.000	....	515,423	46,667	....	23,636	Do.
F	2	4	1.002	....	582,100	46,322	....	23,430	Do.

THE ELASTIC LIMIT AS A PROVING STRAIN.

The *limit of elasticity*, or that point in the strength of material at which it ceases to possess the power to return to its original dimensions when released from an applied strain, has by common consent been adopted as a point to which it is safe and prudent to increase a steadily applied strain by way of "proof."

If this point were for each kind of material a fixed and well understood one, there would be little difficulty and no danger, involved in its use; or were it to be found with certainty between well-defined margins, due care would enable its use with safety. But, unfortunately, it so happens that of all of the characteristics of wrought iron, this factor is the most variable, and affected by most causes.

Our experiments show that it varies not only with different irons, but with bars of the same iron differing in diameter, and with bars of the same iron made with every attention to uniformity, through slight and perhaps unnoticed incidents connected with the manufacture.

For example: Our records show in the history of the very carefully made "iron F" (second lot), that between the elastic limit of two bars of the same diameter a difference of over 30 per cent. occurred, apparently caused by one of the bars having, while in the pile, been heated somewhat more than the other. And with iron Fx, also prepared with great care, the object being to secure uniform tensile strength, the variation in elastic limit amounted to nearly 4,000 pounds per square inch, the tensile strength being very uniform.

With such important functions depending upon it, it seems that all information tending to fix, even approximately, the limit of this factor must be valuable.

We have, therefore, while making tension tests, observed the point at which an appreciable change of form occurred, and we find that with ordinary wrought iron the marginal limit can be determined with considerable exactness.

For convenience in reference, the following table has been arranged, in which are given the ratios we have found between the elastic and tensile limits of a number of irons, as determined by over 800 tests, of which 648 were upon full-sized bars and 220 upon cylinders turned from the cores.

Ratios between elastic and tensile limits as found by means of 868 tests.

Iron.	Bars, full size.		Turned cylinder.	
	No.	Ratio.	No.	Ratio.
		Per cent.		*Per cent.*
CC	......	......	18	60.9
RW	......	......	18	61.4
CCB	......	......	18	64.7
H. I.	29	56.2	17	67.7
A	32	59.7	17	59.0
B	10	62.5	......	......
C	20	60.6	......	......
D	26	60.1	14	66.6
E	22	55.2	......	......
F 1	16	62.1	22	66.8
F 2	53	62.8	25	71.9
F 3	26	68.4	9	74.7
F small	......	......	24	69.4
F large	......	......	20	55.6
Fx 1	45	64.3	......	......
Fx 2	27	67.0	......	......
Fx 3	18	64.9	......	......
K	21	59.6	18	56.4
M	239	63.5	......	......
N	18	62.1	......	......
O	9	64.2	......	......
P	27	63.6	......	......
Px	10	62.9	......	......
Total	648	62.2	220	64.6

CC, contract chain; RW, the same reworked; CCB, the same mixed with boiler iron; H. I, blooms of experimental cable.

From which may be deduced that the average limit of elasticity is not far from 62 per cent. of the tensile strength, and that variations from this mean of more than 5 per cent. are rare.

The extreme variations in the above table are caused by the action of iron F, in whose record is included the history of bars varying in diameter from 3″ to ¼″.

The elastic limits from which the foregoing results are deduced are those obtained by noting the first perceptible stretch, as described. The degree of dependence to be placed upon this method may be judged by the following series of comparative tests, one of each pair of test-pieces whose test is given having been tested by each method—with one the instant of first stretch being noted, the strain not ceasing to accumulate; with the other repeated stoppages took place, and the dimensions were noted with a magnifying glass.

The time occupied by the first method was practically none; by the second at least half an hour on each specimen.

The approximation of the results shows that our system was sufficiently accurate for all practical purposes.

Comparison of the elastic limit as obtained by careful test and by observing first stretch.

Name of iron.	Size of bar.	Elastic limit by— Careful test.	First stretch of cylinder.	First stretch of entire bar.	Name of iron.	Size of bar.	Elastic limit by— Careful test.	First stretch of cylinder.	First stretch of entire bar.
	In.	*Lbs.*	*Lbs.*	*Lbs.*		*In.*	*Lbs.*	*Lbs.*	*Lbs.*
D	2	23,250	25,263	34,559	F	1½	36,437	36,407	35,087
D	1⅝	24,345	24,284	30,000	F	1⅜	....	....	39,103
D	1	34,900	....	33,485	F	1¼	40,534	40,554	39,608
F	4	23,490	23,430	....	F	1⅛	....	37,771	35,493
F	3¾	23,704	23,636	....	F	1	38,802	39,650	39,066
F	3½	24,995	24,951	....	Fx	2	31,830	31,800	34,702
F	3¼	24,750	24,591	....	Fx	1⅝	32,070	31,942	34,235
F	3	24,170	26,400	....	Fx	1	35,714	35,523	34,279
F	2¾	25,280	26,333	....	K	1⅞	28,664	28,664	....
F	2½	30,610	29,941	29,758	K	1¹¹⁄₁₆	26,058	27,539	....
F	2¼	31,880	32,163	31,267	Cx	1⅜	26,220	26,526	33,426
F	2	32,480	31,892	35,864	Cx	1	30,027	30,799	36,960
F	1⅞	37,168	37,416	35,615	Dx	1⅜	26,500	26,520	35,026
F	1¾	39,009	38,902	35,954	Dx	1	30,560	30,430	....
F	1⅝	33,967	34,208	35,394					

Record in detail of the tests by which the elastic limit of pieces in previous table were obtained.

Name of iron.	Size of bar.	Original dimensions of test-piece. Length.	Original dimensions of test-piece. Diameter.	Last stress at which no change had occurred.	Stress at which change of form was observed.	Dimensions of test-piece after stress was relaxed. Length.	Dimensions of test-piece after stress was relaxed. Diameter.	Amount of change by stress. Elongation.	Amount of change by stress. Reduced diameter.	Elastic limit per square inch.	Remarks.
	"	"	"	*Pounds.*	*Pounds.*	"	"	"	"	*Pounds.*	
D	2	4.860	1.000	18,200	18,250	4.862	1.000	0.002	0.000	23,350	
D	1⅝	2.980	0.725	10,000	10,050	2.990	0.721	0.010	0.004	24,345	
D	1⅛	2.520	0.520	7,300	7,400	2.530	0.497	0.030	0.497	34,900	
F 3d	1	2.568	0.504	7,700	7,750	2.648	0.497	0.080	0.007	38,800	
F 3d	1⅛	....	....	....	....	...	....	....	....	Lost.	
F 3d	1¼	2.674	0.552	9,600	9,700	2.680	0.549	0.006	0.003	40,534	
F 3d	1⅜	2.965	0.601	....	10,150	3.007	0.595	0.042	0.006	39,103	
F 3d	1½	3.182	0.650	11,900	12,090	3.185	0.648	0.003	0.002	35,087	
F 3d	1⅝	3.642	0.727	14,000	14,140	3.644	0.727	0.002	0.000	....	About half a thousandth reduction.
F 3d	1¾	3.975	0.802	19,680	19,700	....	....	....	....	35,804	
F 3d	1⅞	4.187	0.877	22,400	22,450	4.323	0.862	0.136	0.015	37,158	
F 3d	2	4.989	0.997	25,250	25,850	5.086	0.986	0.097	0.011	32,480	
F 3d	2¼	4.816	0.997	24,000	25,000	4.917	0.989	0.077	0.008	31,880	
F 3d	2½	4.846	0.995	23,700	23,800	4.923	0.988	0.083	0.008	30,610	
F 3d	2¾	4.904	1.000	19,750	19,850	4.945	0.997	1.041	0.003	25,280	
F 3d	3	4.904	1.001	19,000	19,100	4.928	0.998	0.024	0.003	24,170	
Fx	1	2.490	0.500	6,950	7,000	2.509	0.495	0.019	0.005	35,714	
	1⅝	3.050	0.724	13,100	13,200	3.060	0.719	0.010	0.005	32,070	
	2	4.992	1.000	24,950	25,000	5.104	0.987	0.112	0.013	31,830	
Cx	1⅜	2.983	0.601	7,500	7,550	2.992	0.599	0.009	0.002	26,220	
Cx	1	2.494	0.497	5,950	6,000	2.516	0.490	0.022	0.007	30,927	
Dx	1⅜	3.016	0.600	....	7,500	....	....	....	....	26,500	
Dx	1	2.505	0.500	5,950	6,000	2.520	0.498	0.015	0.002	30,560	

Record in detail of the tests by which the elastic limit of pieces, &c.—Continued.

Name of iron.	Size of bar.	Original dimensions of test-piece.		Last stress at which no change had occurred.	Stress at which change of form was observed.	Dimensions of test-piece after stress was relaxed.		Amount of change by stress.		Elastic limit per square inch.	Remarks.
		Length.	Diameter.			Length.	Diameter.	Elongation.	Reduced diameter.		
	"	"	"	*Pounds.*	*Pounds.*	"	"	"	"		
F....	3½	4.990	0.999	19,300	19,400	4.996	0.998	0.006	0.001	24.750	Seamy and open.
F....	3½	4.970	0.999	19,150	19,250	4.975	0.997	0.005	0.002	24.555	
F....	3½	4.970	1.002	20,100	20,200	4.976	1.000	0.006	0.002	25.620	Seamy and slight cracks.
F....	3½	5.000	0.999	19,000	19,100	5.005	0.998½	0.005	0.005	24.370	More open than the first.
F....	3¾	4.900	1.000	19,000	19,100	4.910	0.998	0.010	0.002	24.319	
F....	3¾	4.900	1.002	18,100	18,200	4.910	0.997	0.010	0.005	23.090	
F....	4	4.900	1.002	18,150	18,250	4.915	0.998	0.015	0.004	23.140	Seamy and very open.
F....	4	4.900	1.002	18,700	18,800	4.920	1.000	0.020	0.002	23.840	Do.

The large barsdiffered from the small ones of same iron, in that the fiber was coarser and more open, and in no case did the specimen, after once beginning to stretch, recover its original dimensions.

INVESTIGATION OF THE EFFECT OF DIFFERENCES IN THE AMOUNT OF REDUCTION BY THE ROLLS.

In procuring material upon which to make tests by tension, both in the bar and link form, our custom was to purchase from manufacturers at least one bar of each size ordinarily used in chain cables. Testing these bars in their normal condition by tension, it became evident that the strength of the different sizes was not in proportion to their areas; but that, on the contrary, there existed a variation in proportional strength which was in accord with variations in the diameter of the bars. In general terms it was found that as the diameter of the bars became less, the strength per square inch increased; but in comparing the results obtained from a number of such sets of bars, it became evident that the increase of strength between the two extremes of 2″ and 1″ was not created by a series of uniform steps upon each successive reduction, but that there was one point in the reductions where a *decrease* took the place of the usual increase, and that from this point the increase again began, and generally by more rapid steps.

Thus, the 2″ bar was of less strength per square inch than the 1⅞″; it of less than the 1¾″, and it of less than the 1⅝″, but the strength of the 1⅝″ was greater than that of the 1½″; the 1⅜″, 1¼″, 1⅛″, and sometimes the 1″, being each of increased strength in the order given.

We found that with a set of bars of the above sizes the difference in proportional strength between the extremes was from four to six thousand pounds; that the tenacity of the 1⅝″ exceeded that of the 2″ from two to three thousand pounds, and that of the 1½″ from one to three thousand pounds per square inch.

As these variations *did* exist in all uniform irons which we examined, we considered that they would occur generally with other irons, and that, so occurring, their existence should be taken into consideration in any attempt to calculate the strength of links or other articles made from bar-iron of various sizes.

Experiments at the testing-machine afforded no indications by which we could determine anything in regard to the causes of these variations. We therefore undertook to watch all of the processes connected with the manufacture of a "set of bars," in hopes that while so doing we should be able to detect the hidden reason.

At our first visit to a rolling-mill, a set of bars were prepared of carefully selected material, and careful notes were taken during the process of manufacture, which are herewith reproduced.

There were two bars of each size rolled.

NOTES IN REGARD TO MANUFACTURE OF

Iron F.—Second lot.

Size of bar.	Dimensions of piles.	Time in furnace.	Number of passes.		Time in rolls.	Size of bar.	Dimensions of piles.	Time in furnace.	Number of passes.		Time in rolls.
			Square rolls.	Round rolls.					Square rolls.	Round rolls.	
″	″ ″ ″	*h. m.*			*Min.*	″	″ ″ ″	*h. m.*			*Min.*
2	6 x 10 x 26	2 06	15	9	09	1½	6 x 6 x 26	1 26	13	10	05
2	6 x 10 x 26	2 15	15	9	08	1½	6 x 6 x 26	1 32	13	8	05½
1⅞	6 x 10 x 24	2 02	15	9	07	1⅜	6 x 6 x 21	1 00	15	8	05
1⅞	6 x 10 x 24	2 23	15	8	07	1⅜	6 x 6 x 21	1 04	15	8	04
1¾	6 x 10 x 21	1 40	17	9	07	1¼	6 x 6 x 14	1 20	15	8	04
1¾	6 x 10 x 21	1 49	17	9	06	1¼	6 x 6 x 14	1 20	15	8	04
1⅝	6 x 10 x 18	1 35	15	9	06	1⅛	6 x 6 x 12	1 10	15	8	04
1⅝	6 x 10 x 18	1 40	15	9	06	1⅛	6 x 6 x 12	1 10	15	8	04
						1	6 x 4 x 14	1 10	15	8	04
						1	6 x 4 x 14	1 10	15	8	04

A study of these notes indicated that if there proved to exist any marked difference in the characteristics of the different bars, it could not be considered as owing to want of care in their preparation.

No accident caused delays while passing through the rolls, and the number of passes was quite uniform. In two cases there are indications of a possible irregularity, due to irregularity in heating.

The 1⅝″ piles were first taken from the furnace, and although pronounced "not quite hot enough," were rolled. After which the 1½″, which was the next one rolled, was kept in the furnace nearly half an hour. In the records from this bar of 1⅝″, we look for the effect of underheating.

One of the 1⅞″ bars was, through accidental causes, retained in the furnace twenty minutes after the other had been rolled. As during this time the heat was not reduced, it was expected that by the records of the two bars of this size data as to the effect of overheating would be procured: we were not disappointed in either case.

Throughout the entire examination of these bars the action of the 1⅝″ and 1⅞″ differed considerably from that of the other bars, and it seems probable that these differences may be considered as the direct effects of *under* and *over heating.*

The noted differences were as follows:

Under the turning tool.

The majority of the bars turned smoothly, the shavings being pliable and from six inches to three feet in length, and they could be straightened without breaking.

The shavings from the 1⅜" were short, "chippy," and brittle, none exceeding 2", and many not over ½" long, and when handled they broke readily.

Those from the 1⅞" bar, which was overheated, were very long and pliable, a number of them extending to from 20 to 30 feet; they could be not only straightened, but bent backward, against the natural coil, until the ends of a piece 6 inches long could be lapped.

Under impact.

The 1⅜" broke readily with nearly a square break, showing about three-fourths granulous surface.

The 1⅞" withstood extreme impact tests, and after being deeply nicked and bent to angle of hammer face, the specimen was closed down till the ends met, showing a long grey fiber. (See Plate IX, Fig. 2.)

Under tension.

The reduction of area and elongation of the 1⅜" was slight compared to that of the rest of the bars, and two of the five pieces tested broke square close to the clamping heads, showing bright crystalline structure.

The action of the 1⅞" was the reverse, it showing under this test great ductility.

Elastic limit.

Compared with the other bars, the elastic limit of the 1⅜" was but slightly if any affected, those of other bars rolled by same train being as follows: Tested as entire bars, 1⅛", 32,019 pounds; 1¼", 33,322 pounds; 1½", 34,591 pounds, averaging 33,311 pounds, that of the 1⅜" being 34,469 pounds, which is somewhat higher, and may indicate an increase through *under*heating, a deduction which is supported by the contrast in this respect shown by the *over*heated 1⅞" bar, when compared to the other of same diameter and with the other bars rolled from same sized pile.

As shown thus by tests of entire bars:

	Pounds.
Elastic limit, 1⅞", *overheated*	23,297
Elastic limit 1⅞", *not overheated*	33,593
Elastic limit, 1⅝", 1¾", and 2", *not overheated*	30,441

Which shows a manifest lowering of the limit of the entire bar through *overheating*.

Tested by turned cylinders, we procured results as follows:

	Pounds.
Elastic limit 1⅜", *under*heated	37,874
Mean of 1⅛", 1¼", and 1½"	34,344
Mean of 1⅞" not overheated	30,505
Mean of 1⅞" overheated	25,737

Which shows that the slightly increased elastic limit of the 1⅜" was caused principally by the condition of the core, and the difference in strength of the *cores* of the two bars of 1⅞" is *less* than that between the entire bars.

Tensile strength.

TESTED AS ENTIRE BARS.

	Pounds.
1⅜"	52,237
1¼"	52,620
1⅛"	51,456

	Pounds.
1⅞″ overheated	48,670
1⅞″ not overheated	49,508
1¾′	49,738

TESTED AS CYLINDERS.

1⅜″	49,219
1¼″	49,961
1⅛″	49,541
1⅞″ overheated	48,560
1⅞″ not overheated	49,073
1¾″	49,549

From which may be drawn the inference that a slight irregularity in heating produces no great effect upon the tensile strength, but apparently lowers it somewhat.

The causes which produced the irregularity in heating of the bars of 1⅝″ and 1⅞″ were such as in all probability occur frequently in all rolling mills, and which, in consequence, enter as a hitherto-unnoticed, but quite important, factor in the manufacture of iron bars; the approach of dinner time hurried up the rolling of the 1⅝″ piles, and the time occupied by the men at dinner delayed the 1⅞″—also, to a less extent, the piles for 1¾″ and 2″.

No other exception to extreme regularity occurred, and we were forced to search for the solution of the problem, in some parts of the processes which were consistent with regularity, and in so doing the secret revealed itself. For if, as is generally admitted, variation in the amount of work given to iron produces variations in characteristics, it could but be expected in this case, when an irregular amount was being administered with the greatest regularity, for in the transformation from pile to bar the amount of work varied upon each size.

The sectional area of the pile for the 2″ bar was reduced *twenty fold;* that of the 1⅝″ pile, *thirty fold*, and that of the 1⅛″, *thirty-six* fold; and no two of the intermediate size received the same reduction, the 1½″, for instance, being reduced much less than its predecessor, the 1⅝″, as will be shown.

The *areas* of the *piles* from which the 2″, 1⅞″, 1¾″, and 1⅝″ bars were rolled were the same, viz, 60 square inches; those of the piles from which the 1½″, 1⅜″, 1¼″, and 1⅛″ were rolled were also uniformly equal to 36 square inches, that of the 1″ being equal to 24 square inches. By contrasting the areas of these piles with those of the resultant bars, it will be seen that there was a very different amount of reduction produced by the rolls, as follows:

IRON F.—SECOND LOT.

Size of bar.	Area of pile.	Area of bar.	Bars' area in per cent. of piles.	Size of bar.	Area of pile.	Area of bar.	Bars' area in per cent. of piles.
2″	60 square inches.	3.1416	5.23	1½″	36 square inches.	1.7671	4.91
1⅞″	....do	2.7612	4.60	1⅜″	....do	1.4849	4.12
1¾″	....do	2.4053	4.01	1¼″	....do	1.2272	3.41
1⅝″	....do	2.0739	3.45	1⅛″	....do	0.9940	2.76
				1″	24 square inches.	0.7854	3.27

Thus the bars, as they successively decreased in diameter from 2″ to 1⅝″, inclusive, were reduced by the rolls each to a greater extent than was its immediate predecessor. At the 1½″ size the reduction was but slightly less than with the 2″, but from this point increased up to and including the 1⅛″. This coincidence between the generally observed results and the apparent causes was striking.

The tenacity of these bars agreed to some extent with the amount of reduction, but not so closely as had been expected. Their order of comparison of reduction, and tenacity, as judged by the tests of entire bars and cylinders, was as follows:

Size.	Order of value.			Remarks.	Size.	Order of value.			Remarks.
	Reduction of area.	Tenacity as—				Reduction of area.	Tenacity as—		
		Bar.	Cylinder.				Bar.	Cylinder.	
″					″				
1	2	1	1		1⅝	4	6	4	
1⅛	1	4	2		1¾	5	7	6	
1¼	3	2	3		1⅞	7	8	8	Overheated.
1⅜	6	3	7	Underheated.	2	9	9	9	
1½	8	5	5						

It is to be noted that the *under*heated 1⅜″, which as entire bar ranked No. 3 in tenacity, as a cylinder ranked below most of those less reduced.

Subsequent experiments with other irons led us to believe that *all* of the above bars received so much work that the slight differences between the amounts received by the different ones did not amount to a large proportion of the entire work received; hence that its effect was lost, and, judging by the 1⅜″ bar, it seemed probable that slight and unnoticed irregularities in heating produced effects which canceled that due to variations in reduction. This belief was strengthened by the contrast in action of the 1⅞″ and 1⅜″ bars; the former was, we knew, slightly overheated and the latter rolled at too low a heat.

The proprietor of the rolling-mill was present when this explanation of the irregular strength of different sized bars presented itself, and became so much interested in the result, which seemed to point out a method by which even his remarkably uniform iron could be improved in this respect, that he gave orders to the superintendent, to furnish the Board with all of the material and labor required to carry the investigation through, and, in compliance with these orders, the experiment was repeated, and another set of bars rolled by the same mill, of the same material, the set comprising bars of all sizes, ranging by ⅛″ from 4″ diameter to ¼″ diameter. The iron was very carefully heated, and received a very uniform number of passes through the rolls; the sizes from ¼″ to ⅞″ averaging 12 passes (11 to 13) through rough, and 12 through finishing-rolls; from 1″ to 2″, inclusive, averaging 12 through rough, and 12 through finishing-rolls; and from 2¼″ to 4″, 10 through rough, and 13 through finishing-rolls.

The dimensions of the piles, the proportion borne by the areas of the resultant bars, and the tensile strength and elastic limit per square inch of the bars, as found by tests made upon them entire, and upon cylinders turned from the cores, are given in the following table:

IRON F—THIRD LOT.

Comparisons of the reduction by the rolls, with the effects upon tenacity and elastic limit.

Size of bar.	Area of pile.	Area of bar in per cent. of area of pile.	Tensile-strength.		Elastic limit.	
			Entire bar.	Core.	Entire bar.	Core.
"	*Square inches.*	*Per cent.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*
4	80	15.70	....	46,322	....	23,430
3¾	80	13.80	....	46,667	....	23,636
3½	80	12.03	....	47,000	....	24,951
3¼	80	10.37	....	47,014	....	24,591
3	80	8.83	....	47,761	....	26,387
2¾	80	7.42	....	46,466	....	26,333
2½	80	6.13	47,344	47,428	29,758	29,941
2¼	72	5.52	48,505	49,290	31,237	32,163
2	72	4.36	47,872	48,280	35,864	31,892
1⅞	36	7.67	49,744	49,370	35,615	37,042
1¾	36	6.68	50,547	48,792	35,954	38,992
1⅝	36	5.76	50,529	49,144	35,394	34,208
1½	36	4.90	50,820	51,838	35,087	36,467
1⅜	36	4.12	52,339	48,819	30,103	....
1¼	36	3.41	52,729	49,801	39,608	40,534
1⅛	25	3.96	50,149	50,530	35,493	37,771
1	25	3.14	51,921	51,128	39,066	38,596
⅞	12¼	4.91	50,716	50,374	33,931	33,204
¾	12¼	3.60	50,673	50,276	33,933	35,933
⅝	12¼	2.50	52,297	51,431	34,450	34,545
½	9	2.17	52,275	52,775	38,445	39,126
⅜	9	3.68	54,008	54,108	38,475	40,213
¼	3	1.60	57,000	59,585	Lost.	Lost.

A study of the preceding table, in connection with the subject under investigation, shows, first, that upon the nine successively decreasing sizes, viz, from 4" to 2", there was but one exception to a constant rise in *tenacity* accompanying the increase of reduction by the rolls, and that the elastic limit rose upon each successive reduction with two exceptions, which are very slight, it falling off 350 pounds in one and 67 pounds in another instance; the tenacity of the 2" (4.36 per cent. of pile) being over that of 4" (15.70 per cent. of pile) 1,106 pounds and the elastic limit 8,462 pounds.

From 1⅞" (7.67 per cent. of pile) to 1¼" (3.41 per cent. of pile) the iron was somewhat irregular, and there was but a slight rise in tenacity, viz, 431 pounds, but in the elastic limit the rise was 4,993 pounds.

The tenacity of the ⅞" (4.91 per cent. of pile) was but 104 pounds greater than that of 1½" (4.90 per cent. of pile), that of ⅝" (2.50 per cent. of pile) nearly corresponding with that of 1⅜" (4.12 per cent. of pile).

The effect of the reduction was most marked on the smaller sizes, the ½" (2.17 per cent. of pile) having nearly 5,000 pounds less tenacity than the ¼" (1.60 per cent. of pile).

The notes taken at the mill do not indicate that either bar was under or over heated, but, judging by the results of the previous experiment, there are indications that the 1½" bar was *overheated*, inasmuch as the strength of the core exceeded that of the entire bar.

So far as this experiment was expected to account for the usually found greater strength of the 1⅜" bar it proved a failure, for it was weaker than the bars immediately succeeding or preceding, but we considered that the information gained as to the probable effect of *under* and *over* heating was of value.

The indications being that if a bar is *underheated* it will have an unduly high tenacity and elastic limit, and that if *overheated* the reverse will be the case; further, that if *under*heated the strength obtained by a cylinder, turned from the core, will be less than that which would be obtained by testing the entire bar, if the diameter be small, and greater if the cylinder is turned from a large bar.

It is possible that the above two points are interdependent, as the large bars are more apt to be irregularly heated than the small ones, and some portions of the pile must be in a state fit to roll before other portions are sufficiently heated; *these overheated* portions we turn off from the bar to produce the cylindrical test-piece.

As in the previous experiment, we believed that the thorough work received by all sizes put them in a condition which prevented the effect due to a slight difference in the reduction being plainly manifest. We therefore selected for another experiment the bars of a very slightly worked iron, viz, iron N.

IRON N.

Dimensions of piles, areas of piles, of bars in percentage of those of piles, tenacity, elastic limit, &c.

Size of bar.	Dimensions of piles.	Area of piles.	Area of bars in per cent. of area of piles.	Tensile strength.	Elastic limit.
Inches.	*Inches.*	*Square inches.*	*Per cent.*	*Pounds.*	*Pounds.*
2	6 x 4½ x 26	27	11.63	51, 848	32, 461
1⅞	6 x 4½ x 21	27	10.22	54, 034	33, 610
1¾	6 x 4½ x 21	27	8.90	55, 018	34, 283
1⅝	6 x 4½ x 16½	27	7.68	56, 344	35, 889
1½	4 x 3¾ x 25	15	11.78	53, 550	34, 690
1⅜	4 x 3¾ x 23	15	9.90	54, 277	33, 622
1¼	4 x 3¾ x 17	15	8.18	56, 478	33, 251
1⅛	4 x 3¾ x 16	15	6.62	56, 143	32, 267

The above results supplied the missing evidence; with few exceptions the tenacity and elastic limit increased upon each successive increase in the amount of reduction by the rolls, as shown more plainly thus, where they are arranged in the order of their reduction:

Size.	Precedence in—			Remarks.
	Reduction.	Tensile strength.	Elastic limit.	
Inches.				
1⅛	1	8	8	
1⅝	2	1	1	
1¼	3	2	6	
1¾	4	4	3	
1⅜	5	5	4	
1⅞	6	8	5	
2	7	7	7	
1½	8	6	2	

The tensile strength of 2″ bar was probably greater than recorded, the iron being so brittle that the head of test-piece pulled off, and the bar could be broken by sledge blows without previous nicking. This iron, under every form of test, showed by its marked contrast with iron F the disadvantages which follow too little work.

IRON A.

Our next experiment was with iron A, and the dimensions of the piles, areas of bars in percentage of that of piles, tenacity, elastic limit, &c., are given in the following table.

The piles of this iron were for the four largest sizes 10″ x 10″, and for the other five sizes 8″ x 9″; these were reduced by the steam-hammer to 6″ x 6″ and 5″ x 5″. As with the previous irons, we have neglected all preliminary work and based our research upon the effects of the final rolling alone, we do the same in this instance.

IRON A.

Size of bar.	Area of pile.	Area of bar in per cent. of area of pile.	Tensile strength.	Elastic limit.	Remarks.
Inches.	*Square inches.*	*Per cent.*	*Pounds.*	*Pounds.*	
2	36	8.72	50,171	27,600	
1⅞	36	7.67	50,850	27,500	
1¾	36	6.68	51,509	29,400	
1⅝	36	5.76	54,344	32,900	Underheated when rolled.
1½	25	7.07	51,884	28,800	
1⅜	25	5.94	53,557	33,000	
1¼	25	4.90	53,879	27,600	
1⅛	25	3.98	53,085	27,650	
1	25	3.14	54,690	30,500	

The preliminary hammering had undoubtedly a great effect upon this iron, which was made by combining old, very coarse, and brittle chain-iron, with old boiler-iron, and in regularity and uniformity was very liable to prove a direct contrast to iron F, which was carefully made of select material, yet we find the same law operating.

On the first four sizes every decrease in the percentage of the piles area given to the bar was followed by an increase of *tenacity* and a *higher* elastic limit.

The 1⅜″, through accident, got quite cool before it was rolled, which probably increased its tenacity. With the five smaller sizes there was a marked increase between the extremes; the 1½″ (7.07 per cent. of pile) having tenacity 2,806 and elastic limit 1,700 pounds *less* than the 1″ (3.14 per cent. of pile).

The elastic limit was generally low, but in this respect this iron possessed a feature peculiar to itself—it was made of materials differing greatly in strength, and the weakest, or boiler-iron, stretched first, then the other iron; but once stretching together, it would resist increased stress with very slight change. It stretched in parts, but broke as a unit.

IRON P.

The manufacturer of iron P having complied with our request, by causing notes to be taken during the manufacture of a set of bars furnished, we were able to obtain from its record more confirmatory data.

EXPERIMENTS WITH IRON P.

This iron was made in this manner: puddled iron bars, 3″ and 6″ wide, were piled endwise and crosswise; this pile was then heated and hammered into a bloom 8″ square, which was rolled into bars 6″ wide and ¾″ thick, which were piled lengthwise, ten deep, making a pile 6″ x 7½″, for all sizes from 2″ to 1¼″, inclusive.

The 1⅛″ and 1″ bars were made from billets 3½″ square, rolled from the blooms, then reheated and rolled to the required sizes.

The dimensions of piles, &c., are given in the following table:

IRON P.

Size of bar.	Area of pile.	Area of bar in per cent. of area of pile.	Tensile strength.	Elastic limit.
Inches.	*Square inches.*	*Per cent.*	*Pounds.*	*Pounds.*
2	45	6.98	50,834	31.878
1⅞	45	6.18	52,800	32.318
1¾	45	5.34	52,849	33.482
1⅝	45	4.60	55,634	33.522
1½	45	3.91	54,145	33.140
1⅜	45	3.30	55,230	34.762
1¼	45	2.72	56,871	36.868
1⅛	45	2.21	57,498	Lost.
1	45	1.74	59,755	39.230

In this case there was but one exception to the constant increase of tenacity and elastic limit produced by the increased reduction by the rolls.

The 1⅝″ bar, through some unknown cause, differed greatly from the others, both in action under stress and in appearance of fracture.

All of the others showed great reduction of area and close fibrous structure; this bar broke with almost imperceptible reduction, and showed a bright crystalline surface.

This iron was excellent bar-iron, but had received too much work for cable-iron, its welding qualities being impaired, and the forging necessary to produce the link reduced the strength of the part forged.

The manufacturers prepared another set of bars, one course of heating and hammering being omitted. The iron was piled, also, in a different manner from P, as will be seen in the following table, which gives the data embraced in the previous table.

This iron was distinguished as P*x* (or P experimental).

IRON P*x*.

Size of bar.	Area of pile.	Area of bar in per cent. of area in pile.	Tensile strength.	Elastic limit.
Inches.	*Square inches.*	*Per cent.*	*Pounds.*	*Pounds.*
2	49.5	6.35	52,599	31,198
1⅞	45	6.13	51,762	32,261
1¾	42	5.72	54,212	33,908
1⅝	40.5	5.21	54,689	33,427
1½	40.5	4.86	54,354	34,617
1⅜	36	4.11		
1¼	31.5	3.89	56,334	33,921

The results are irregular, but as between the extremes of size are confirmatory of the previous experiments.

Further confirmation was obtained in an indirect manner by the results of tension-tests upon iron E. We tested two sets of bars of this iron furnished at different times; with each set we found that the falling off of strength, usually occurring at the 1½″ size, did not take place, but that, on the contrary, the 1½″ possessed more tenacity than the 1⅝″, and the 1⅜″ much less; thus:

First set, 2″, tensile strength, 51,152; 1⅝″, 52,000; 1½″, 55,415; 1⅜″, 52,254 pounds.

Second set, 1⅝″, 52,675; 1½″, 54,544; 1⅜″, 53,900 pounds.

Upon purchasing a third set of bars (which have not yet been tested), the dimensions of the piles, together with all data as to the construction of the iron, were also furnished, and upon the assumption that the manner described is the usual manner by which bars are rolled at this mill, we find an explanation of the low tenacity of the 1⅜'' bars of preceding lots.

NOTES IN REGARD TO MANUFACTURE OF UNTESTED BARS OF IRON E.

Size of bar.	Area of pile.	Area of bar in per cent. of area of pile.	Size of bar.	Area of pile.	Area of bar in per cent. of area of pile.
Inches.	*Square inches.*	*Per cent.*	*Inches.*	*Square inches.*	*Per cent.*
5	63	31.17	2¼	40¼	9.88
4¾	63	28.13	2	35	8.98
4½	52½	30.28	1⅞	35	7.89
4	52½	23.95	1¾	29¾	8.08
3¾	52½	21.04	1⅝	29¾	6.93
3½	37½	25.65	1½	29¾	5.94
3¼	37½	22.12	1⅜	13¼	11.20
3	37½	18.85	1¼	13¼	9.26
2¾	37½	15.84	1⅛	13¼	7.50
2½	40¼	12.19	1	9⅝	8.16

When this series of bars is tested by the testing-machine of the Board, if their tenacity, &c., corresponds with the above reduction, we will be still more assured as to the effect upon the same material of different amounts of reduction.

The evidence submitted is of sufficient value to justify us in asserting that variations in the amount of reduction by the rolls of bars from the same material produce fully as much difference in their physical characteristics, as is produced by differences in their chemical constitution.

EXPERIMENTS UNDERTAKEN WITH THE PURPOSE OF PRODUCING UNIFORM TENSILE STRENGTH IN BARS OF VARIOUS SIZES.

In order to ascertain beyond question if the rule would work both ways, and uniform tenacity be secured by uniform reduction, a series of experiments was carried on at the rolling mills where those upon iron F had been made. The material (crude and reheated slabs) was given to us by the mill owner, and was identical with that from which iron F was rolled.

Three sets of bars from 1'' to 2'' were rolled during this research, which are called in this report F*x*, Nos. 1, 2, and 3; the first two sets were not successful, the testing-machine showing our failure; the third proved a success.

The following is a brief history of these experiments:

First experiment.

F*x*, No. 1.

In preparing the piles for the first set, they were so graduated that the percentage of the piles' area borne by the bar should increase slightly upon each reduction in diameter of the bar, it being believed that the additional work thus given to the smaller sizes would in a measure counteract the possible differences which might be due to overheating of the large and underheating of the small bars.

The dimensions of piles, &c., are given in the following table, together with the tensile strength, elastic limit, &c., of the resultant bars:

F*x* No. 1.

Dimensions of piles, of bars in per cent. of area of piles, tenacity and elastic limit of series of bars.

Size of bars.	Dimensions of piles.	Area of piles.	Area of bars in per cent. of area of piles.	Tensile strength.	Elastic limit.	Remarks.
Inches.	*Inches.*	*Square inches.*	*Per cent.*	*Pounds.*	*Pounds.*	
2	8 x 10	80	3.93	52,011	34,702	
1⅞	8 x 9	72	3.83	52,874	35,641	
1¾	8 x 8	64	3.75	53,846	36,573	
1⅝	6 x 10	60	3.45	53,537	34,235	
1½	6 x 9	54	3.27	53,491	34,307	
1⅜	6 x 8	48	3.09	52,968	33,275	Averages 53,121 T. S. and 34,700 E. L.
1¼	6 x 8	48	2.55	55,807	34,784	
1⅛	6 x 6	36	2.76	56,434	34,682	
1	6 x 5	30	2.62	55,770	34,279	Averages 55,837 T. S. and 34,582 E. L.

The results show a nearly uniform tenacity for the first six sizes, then an increase, which remains quite uniform for the other three, the elastic limit remaining very uniform throughout.

The tenacity of the 2″ bar, rolled by the usual process (iron F, 2″), its area being 5.23 per cent. of pile, was 47,569 pounds, showing an increase upon this size by the experimental process of 4,442 pounds; and the increase in the elastic limit (5,910 pounds) was still more marked.

No explanation, except that they were possibly not enough heated, accounts for the increased tenacity of the 1⅛″ and 1″ bars; the 1¼″ was by mistake rolled from too large a pile.

Weighing the merits of this iron as adapted for cable, it is evident by our tests that although the increase of work improved it as bar-iron, yet as cable-iron it was *not* so valuable as that made of the same material by the usual processes; and further, that although the strength of the entire bars was increased by the extra work, yet that of the core of the iron was not, as shown by the following tests:

Tensile strength and elastic limit of three bars iron Fx, as found by rupture of entire bars and of turned cylinders.

Size.	Tensile strength.		Elastic limit.	
	Entire bar.	Cylinder.	Entire bar.	Cylinder.
Inches.	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*
2	52,011	45,964	34,702	31,830
1⅝	53,537	47,124	34,235	32,070
1	53,570	49,656	34,279	35,714

The difference in each factor diminishing as the diameters decrease.*

With iron F*x* the small bars were not so much overworked as the larger ones. Tests by impact showed that while the bars were entire those which had received the most work were stiffer than the others, but that a slight cut through the skin reversed their value. The blows were of a

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*A similar difference between the elements of tensile strength and elastic limit as given by entire bar and cylinder occurs in a greatly overworked bar of iron D, a soft rivet mixture.

100-pound hammer dropped 30 feet, and the deflection at each blow being noted, proved as above stated.

Comparison of the effects produced by impact upon bars of irons F and Fx.

		Bars not nicked.								Bars nicked.						
		Deflection produced by each blow.								Deflection produced by each blow.						
Iron.	Size.	1st.	2d.	3d.	4th.	5th.	6th.	7th.	8th.	1st.	2d.	3d.	4th.	5th.	6th.	
	Inch.	°	°	°	°	°	°	°	°	°	°	°	°	°	°	
F	2	22	35	48	60	79	85	96	109	18	31	45	62	90	110	
Fx	2	19	32	46	58	73	80	90	107	37	50	63	67	95	.....	
F	1⅞	27	43	62	78	100	109	.....	.....	23	Broke.	.....	.....	.....	.....	
Fx	1⅞	25	41	58	70	90	98	.....	.....	40	75	95	107	.....	.....	
F	1¾	34	60	72	95	110	.....	.....	.....	39	Broke.	.....	.....	.....	.....	
Fx	1¾	30	50	70	90	110	.....	.....	.....	45	70	110	.....	.....	.....	
F	1⅝	39	64	90	111	.....	.....	.....	.....	Broke.	.....	.....	.....	.....	.....	
Fx	1⅝	35	60	90	110	.....	.....	.....	.....	85	100	.....	.....	.....	.....	
F	1½	46	82	107	.....	.....	.....	.....	.....	27	55	.....	.....	.....	.....	*a*
Fx	1½	40	80	107	.....	.....	.....	.....	.....	65	Broke	.....	.....	.....	.....	
F	1⅜	60	97	118	.....	.....	.....	.....	.....	90	.....	.....	.....	.....	.....	*a*
Fx	1⅜	57	98	120	.....	.....	.....	.....	.....	75	110	.....	.....	.....	.....	
F	1¼	76	110	.....	.....	.....	.....	.....	.....	Broke.	.....	.....	.....	.....	.....	*a*
Fx	1¼	72	112	.....	.....	.....	.....	.....	.....	90	112	.....	.....	.....	.....	
F	1⅛	103	.....	.....	.....	.....	.....	.....	.....	Broke.	.....	.....	.....	.....	.....	*a*
Fx	1⅛	90	112	.....	.....	.....	.....	.....	.....	110	.....	.....	.....	.....	.....	
F	1	112	.....	.....	.....	.....	.....	.....	.....	Broke	.....	.....	.....	.....	.....	*a*
Fx	1	110	.....	.....	.....	.....	.....	.....	.....	110	.....	.....	.....	.....	.....	

The blows marked "*a*" being from 2,000 to 1,000 foot-pounds less than those given to the other bars. All of the pieces were of uniform proportional length (12 diameters) and treated uniformly.

Thus, throughout, the bars of iron F*x*, when not nicked, withstood, with less deflection than iron F, the same blows; when nicked, the case was reversed, except in the case of a few bars of F, which broke at fewer blows than F*x* resisted, from which data we argue that the increase of work strengthened the outer portion of the bar much more than it did the interior, and that the elastic limit was raised with the strength, the bars thus gaining in resilience and tenacity.

As cable, the welding qualities of F*x* were inferior to those of F, and this inferiority was greater with the larger bars.

F*x*, NOS. 2 AND 3.

A second attempt to produce a set of bars of uniform tenacity resulted in a complete failure, due, we were assured, to a misunderstanding in regard to heating the piles, but on a third attempt we were successful, as shown by the following table, in which the usual data are given:

F*x* No. 3.

Dimensions and areas of piles, areas of bars in percentages of areas of piles, tensile strength, elastic limit, &c., of nine bars.

Size of bar.	Dimensions of piles.	Area of piles.	Area of bars in per cent. of area of piles.	Tensile strength.	Elastic limit.	Size of bar.	Dimensions of piles.	Area of piles.	Area of bars in per cent. of area of piles.	Tensile strength.	Elastic limit.
Inches.	*Inches.*	*Sq. in.*	*Per ct.*	*Pounds.*	*Pounds.*	*Inches.*	*Inches.*	*Sq. in.*	*Per ct.*	*Pounds.*	*Pounds.*
2	8 x 10	80	3.92	50,763	33,258	1⅜	6 x 7	42	3.53	52,733	34,606
1⅞	8 x 10	80	3.45	53,361	35,032	1¼	6 x 6	36	3.41	53,248	33,520
1¾	8 x 9	72	3.34	53,154	35,323	1⅛	6 x 5	30	3.31	54,648	34,695
1⅝	8 x 8	64	3.24	53,329	33,520	1	5 x 5	25	3.14	53,915	36,287
1½	6 x 9	54	3.27	52,819	34,840						

The pile for the 2″ was necessarily too small, as there were no rolls in the mill which would take a larger pile. The record is however of value as a contrast to that of the other eight bars, the average of whose tensile strength, 53,401 pounds, and of elastic limit, 34,365 pounds, is but slightly varied from by any of the bars.

It is assumed that the record of the foregoing bars is sufficient to establish more firmly the assertion already made in regard to the effect of different amounts of reduction.

Two practical results of value may be deduced from this investigation of the action of the rolls.

The first is, that as important differences exist in the proportionate strength of different-sized bars made of the same material, which are due entirely to differences in the processes by which they are manufactured, and as the elimination or reduction of such differences would necessitate such a great and expensive change in the system by which the bars are produced that it is not probable that it will be often attempted, it is necessary that these differences should be taken into consideration when estimates of the strength of any structure in which rolled wrought iron of different sizes is introduced are made, and in all tables of strength based upon the strength of such bars.

Second, that where the increased value of the bars will justify the increased expense of their production, those of 2″ diameter can be increased in strength over 15,000 pounds, and it is not improbable that bars of 4″ diameter can have the strength increased over 60,000 pounds, as opposed to direct tension, with no loss in their power to resist sudden strains.

The Bar—Part II.

TABULATED RECORDS IN DETAIL OF THE RESULTS OBTAINED FROM TENSION TESTS UPON OVER TWO THOUSAND TEST-PIECES OF DIFFERENT WROUGHT IRONS.

GIVING THE APPROXIMATE ELASTIC LIMIT, THE ULTIMATE STRENGTH AS OBSERVED AND REDUCED TO VARIOUS AREAS, THE ELONGATION AND REDUCTION OF AREA.

THE TESTS HAVING BEEN MADE IN INVESTIGATIONS OF THE CHARACTER OF THE IRON—COMPARISON OF STRENGTH OF ROUGH AND TURNED BARS—EFFECT OF VARIATIONS IN REDUCTION FROM PILE TO BARS, AND OF UNIFORMITY—ELEVATION OF THE LIMIT OF STRESS, AND OF VARIATIONS IN RAPIDITY OF APPLICATION OF STRESS.

Tension-tests upon round bars of rolled iron.

Investigation—Survey of contract chain-iron on hand at navy-yard, Washington. *Test-pieces*—Turned cylinders. *Testing-machine*—B.

Iron—CONTRACT CHAIN-IRON.

Bar.		Dimensions of test-pieces.						Stress in pounds at—			Ratio of elastic to tensile limit.	Marked.	Remarks.
		Diameter.		Length.		At fracture.							
Test number.	Approximate diameter of bar.	Original.	At fracture.	Original.	At fracture.	Reduced area.	Per cent. of elongation.	Elastic limit per square inch.	Tensile limit observed.	Tensile limit per square inch.			
	"	"	"	"	"								
1	2¼	.874	.787	3.50	4.37	69.2	24.9	31,172	30,550	50,925	67.1	C	Coarse, granular.
2	"	.875	.689	3.50	4.48	62.0	28.0	31,598	30,950	51,471	61.4	R	Improved.
3	"	.875	.701	3.50	4.40	64.2	25.7	31,598	30,450	50,640	62.4	M	Granular and fiber.
4	2 3/16	.872	.792	3.50	+.02	82.5	13.3	33,908	28,750	48,141	70.4	C	Gran. & very coarse.
5	"	.875	......	3.50	3.91	......	11.7	34,259	30,525	50,527	67.4	R	Much improved.
6	"	.875	.740	3.50	4.06	71.5	16.0	34,092	30,750	51,139	67.0	M	Granular and fiber.
7	2⅛	.976	.794	3.90	4.94	66.2	26.7	27,466	35,950	48,048	57.2	C	Granular and fiber.
8	"	.976	.825	3.90	4.77	71.4	22.3	35,204	39,160	52,339	67.2	R	Improved.
9	"	.976	.768	3.90	4.92	61.9	23.6	32,578	38,875	51,958	62.7	M	Do.
10	2	.976	......	3.92	4.90	......	25.0	28,338	34,700	46,378	61.1	C	Coarse, granular.
11	"	.976	.753	3.92	5.06	59.5	29.1	34,521	40,225	53,762	64.2	R	No improvement.
12	"	.976	.804	3.88	4.74	67.9	22.2	32,181	38,650	51,657	62.3	M	Granular and fiber.
13	1 15/16	.976	.772	3.90	4.92	62.2	36.0	31,977	40,250	53,796	59.4	C	Coarse, granular.
14	"	.976	.....	3.90	4.55	......	16.7	37,423	40,875	54,631	68.5	R	No imp. by work.
15	"	.976	.772	3.90	4.93	55.0	26.4	29,404	37,150	49,652	59.2	M	Do.
16	1⅞	.976	.....	3.92	4.75	.....	21.2	33,519	38,000	50,788	66.0	C	Coarse, granular.
17	"	.976	.754	3.92	5.02	59.7	28.0	32,649	38,000	50,788	64.3	R	Improved.
18	"	.976	.764	3.92	5.02	61.2	28.0	34,621	39,425	52,693	65.7	M	Do.
19	1 13/16	.976	......	3.87	......	......	......	28,067	37,050	49,519	56.7	C	Coarse, granular.
20	"	.964	.750	3.90	5.10	60.5	29.0	30,141	36,550	50,075	60.2	R	Improved.
21	"	.964	.794	3.90	5.03	69.8	30.8	33,646	36,425	50,958	66.3	M	Do.
22	1¾	.976	.805	3.92	5.00	68.0	27.6	23,559	35,600	47,580	49.5	C	Fine, granular.
23	"	.976	.735	3.92	5.03	56.7	28.3	27,402	38,850	51,924	52.8	R	Improved.
24	"	.976	.740	3.92	5.14	57.5	31.1	26,467	38,525	51,490	51.4	M	Much improved.
25	1 9/16	.565	.455	2.27	2.89	64.8	27.3	35,500	13,350	53,250	66.7	C	Fibrous.
26	"	.564	.478	2.26	2.80	71.8	23.8	33,623	14,025	56,145	59.9	R	Improved.
27	"	.565	.428	2.26	2.85	57.4	30.5	33,008	13,090	52,213	63.2	M	
28	1½	.564	.416	2.23	2.92	54.4	30.9	26,821	11,755	47,138	57.0	C	Dark, coal-like.
29	"	.564	.440	2.23	2.91	60.9	30.9	37,270	13,220	52,922	70.4	R	Improved.
30	"	.564	.436	2.28	3.00	59.8	32.0	34,827	13,125	52,542	65.3	M	Do.
31	1 7/16	.565	.475	2.27	2.80	70.7	23.3	33,075	12,550	50,059	66.	C	Dark, dull fiber.
32	"	.565	.463	2.26	2.89	67.1	27.9	38,093	14,650	58,436	65.2	R	Fiber and granular.
33	"	.565	.500	2.27	2.78	78.3	22.5	35,400	13,975	55,743	63.5	M	Do.
34	1⅜	.565	.450	2.23	2.75	63.4	26.6	29,916	11,825	47,168	63.3	C	Fine gran. and fiber.
35	"	.565	......	2.23	2.60	......	16.6	41,484	13,525	53,949	76.9	R	No improvement.
36	"	.564	......	2.23	2.60	......	16.6	38,431	12,250	49,039	78.4	M	Improved.
37	1 5/16	.565	.465	2.27	2.80	67.7	23.3	30,115	12,300	49,062	61.4	C	Fine gran. and fiber.
38	"	.565	.450	2.27	2.80	63.4	23.3	40,128	14,000	55,843	71.8	R	Improved.
39	"	.565	.455	2.27	2.78	64.8	26.8	37,295	13,370	53,330	69.9	M	Do.

Tension-tests upon round bars of rolled iron—Continued.

Bar.		Dimensions of test-pieces.						Stress in pounds at—			Ratio of elastic to tensile limit.	Marked.	Remarks.
		Diameter.		Length.		At fracture.							
Test number.	Approximate diameter of bar.	Original.	At fracture.	Original.	At fracture.	Reduced area.	Per cent. of elongation.	Elastic limit per square inch.	Tensile limit observed.	Tensile limit per square inch.			
	"	"	"	"	"								
40	1¼	.565	.461	2.26	2.95	66.6	30.5	30,514	12,820	51,136	59.6	C	Dark, fibrous.
41	"	.565	.463	2.26	2.78	67.1	23.0	39,090	14,200	56,641	69.	R	Fiber and granular.
42	"	.565	.480	2.26	2.82	72.2	24.8	39,609	14,025	55,943	70.8	M	Do.
43	1$\frac{3}{16}$	.564	.460	2.27	2.77	66.5	22.	34,928	13,100	52,442	66.8	C	Brt., fiber.
44	"	.564	.468	2.27	2.76	68.8	21.6	39,832	14,375	57,546	69.2	R	Do.
45	"	.564	.450	2.27	2.85	63.6	25.5	38,130	13,850	54,363	70.1	M	Do.
46	1⅛	.565	.410	2.26	2.97	52.6	31.4	30,514	13,050	52,054	58.6	C	Steely, fiber.
47	"	.563	......	2.26	2.75	......	21.7	39,888	14,025	55,943	71.3	R	No improvement.
48	"	.565	......	2.26	2.70	......	19.5	37,216	13,125	52,353	71.	M	Do.
49	1$\frac{1}{16}$	.564	.488	2.26	2.72	74.9	20.4	25,551	14,125	56,545	45.2	C	Brt., steely.
50	"	.564	.491	2.26	2.55	75.8	12.8	47,896	17,450	69,856	68.5	R	No improvement.
51	"	.564	.440	2.26	2.80	60.9	23.8	32,064	14,225	56,945	56.3	M	Much improved.
52	1$\frac{1}{16}$	.564	.416	2.26	3.03	54.4	34.1	35,028	13,750	55,044	63.6	C	Fine, steel-like.
53	"	.564	.451	2.26	2.85	64.0	26.1	36,860	13,650	54,644	67.4	R	No improvement.
54	"	.564	.448	2.26	2.80	63.0	23.8	39,070	14,485	57,968	68.7	M	

Investigations—Comparison of strength of rough and turned bars and of variation in rapidity of application of stress. *Test-pieces*—Turned cylinders. *Testing-machine*—B.

Iron—CONTRACT CHAIN-IRON.

Bar.		Dimension of test-pieces.						Stress in pounds at—			Remarks.
		Diameter.		Length.		At fracture.					
Test number.	Diameter of bar.	Original.	At fracture.	Original.	At fracture.	Reduced area.	Per cent. of elongation.	Elastic limit per square inch.	Tensile limit observed.	Tensile limit per square inch.	
	"	"	"	"	"						
55	½	.517	.419	1.98	2.88	66.0	20.7	....	....	58,837	Rough.
56	"	.518	.418	1.98	2.85	65.1	18.9	....	....	61,700	Do.
57	"	.517	.433	1.98	2.41	70.0	22.5	....	....	60,863	Do.
Av.	....	......	......	....	....	**67.0**	**20.7**			**60,466**	
58	½	.402	.329	1.57	....	67.0	16.5	....	....	59,300	Turned.
59	"	.402	.316	1.56	....	61.6	10.9	....	....	58,700	Do.
60	"	.402	.349	1.60	....	75.0	15.8	....	....	60,500	Do.
61	"	.402	.324	1.58	....	65.0	26.8	....	....	60,285	Do.
Av.	....	......	....	....	....	**67.1**	**17.5**	....	....	**59,690**	
62	2$\frac{3}{16}$	.875	.740	3.50	4.06	71.5	16.0	34.259	30,750	51,139	28 minutes under strain.
63	"	.875	......	3.50	3.91	....	11.7	34,092	30,525	50,751	30 minutes under strain.
64	"	.[illegible]	.738	3.87	4.15	87.8	7.2	32,009	20,650	42,237	5 minutes under strain.
65	"	.782	.668	3.87	4.72	73.0	22.0	33,989	24,250	50,490	7 minutes under strain.

The 2$\frac{3}{16}$″ bar of contract chain-iron was probably of as brittle and coarse a quality as is ever found in rolled iron. By thorough reworking it was greatly improved.

No result of any value is determined by the above test, during which the rate of speed by which rupture was produced was greatly varied.

Tension tests upon round bars of hammered iron.

Investigation—Production of valuable chain-iron from combination of assorted scrap-iron. *Test-pieces*—Bars swaged by hand. *Testing-machine*—A.

Iron—HAMMERED.

(Blooms from which iron A, experimental cable iron, was rolled.)

Bar.		Dimensions of test-pieces.						Stress in pounds.				
		Diameter.		Length.		At fracture.			Tensile limit.			
Test number.	Approximate diameter of bar.	Original.	At fracture.	Original.	At fracture.	Reduced area.	Per cent.; elongation.	Elastic limit per square inch.	Observed.	Per square inch, original area.	Per square inch, fracture area.	Ratio of elastic tensile limit.
	"	"	"	"	"							
66	2	2.02	1.55	6.00	7.72	58.9	29.0	34,199	167,230	51,960	88,623	65.4
67	"	2.06	1.69	9.00	11.18	67.3	24.0	26,403	173,180	52,500	77,209	51.3
68	"	1.95	1.62	6.00	7.50	69.1	25.0	22,059	155,712	52,138	75,550	42.3
69	"	1.95	1.60	10.00	12.54	65.5	25.0	29,000	161,760	54,000	77,003	54.0
70	"	1.99	1.59	13.25	15.95	63.9	20.0	27,781	167,040	53,710	84,108	51.7
71	"	2.02	1.64	10.00	11.98	66.0	20.0	30,600	172,032	53,670	81,454	57.0
72	"	2.03	1.75	8.50	10.15	74.3	19.4	34,939	172,500	53,290	71,725	65.6
73	"	2.03	1.65	8.50	10.35	66.0	22.0	35,217	176,500	54,525	82,577	64.6
74	"	2.02	1.64	8.50	10.40	66.0	22.3	35,295	172,000	53,664	81,439	65.6
75	"	2.02	1.74	8.50	10.15	74.0	19.4	35,444	174,000	54,290	73,129	65.3
Av.	......	......	......	......	......	**67.1**	**22.6**	**31,087**	**169,193**	**53,374**	**79,282**	**58.3**
76	1⅞	1.84	1.39	12.30	15.05	57.1	22.0	31,049	132,480	49,823	87,330	62.3
77	"	1.83	1.45	13.00	15.86	02.8	22.0	30,110	140,160	53,292	84,896	56.5
Av.	......	......	......	.....	......	**60.0**	**22.0**	**30,580**	**136,320**	**51,558**	**86,113**	**59.4**
78	1⅝	1.61	1.28	7.37	8.98	63.2	22.0	29,233	111,360	54,695	86,526	53.4
79	"	1.60	1.21	9.65	11.19	57.2	16.0	28,165	111,360	55,375	96,835	50.9
80	"	1.61	1.32	7.40	8.86	67.2	20.0	27,853	112,800	55,402	82,456	49.8
81	"	1.60	1.25	7.33	8.72	61.1	19.0	29,139	114,240	56,807	93,105	51.3
82	"	1.62	1.28	9.44	11.75	02.5	24.0	33,071	108,480	52,634	84,289	62.8
83	"	1.60	1.23	9.44	11.10	59.1	18.0	34,848	111.300	55,375	93,686	63.0
84	"	1.63	1.23	20.00	24.90	57.0	21.0	28,850	116,000	56,000	97,643	52.0
85	"	1.63	1.25	20.00	23.80	56.8	19.0	29,500	119,000	57,000	96,984	51.8
86	"	1.61	1.17	9.00	10.90	53.0	21.0	29,000	104,852	51,200	97,069	56.1
Av.	......	......	......	......	......	**59.8**	**20.0**	**30,073**	**112,099**	**54,943**	**92,066**	**54.6**
87	1½	1.50	1.16	10.00	12.43	60.0	24.0	28,000	92,040	48,100	87,644	53.9
88	"	1.23	0.97	5.00	5.93	62.3	19.0	25,000	57,280	48,100	75,510	51.9
89	1⅛	1.14	0.80	4.00	5.17	49.3	29.0	24,480	56,100	54,960	111,597	44.5
90	"	1.12	0.82	4.00	4.97	53.7	24.0	24,900	55,542	56,387	105,773	44.2
Av.	......	......	......	......	......	**51.5**	**26.5**	**24,690**	**55,821**	**55,673**	**108,185**	**48.3**
91	......	1.81	1.38	10.00	12.43	58.2	25.0	33,000	139,000	52,420	92,914	61.2
92	......	1.51	1.08	7.38	9.18	51.2	24.0	28,424	91,680	51,217	100,077	55.5
93	......	1.51	1.15	7.40	9.13	58.0	23.0	32,764	92,960	54,167	93,320	60.4
94	......	1.02	.80	4.00	4.72	61.6	18.0	35,000	45,600	55,800	90,710	63.2
Av.	......	......	......	......	......	**57.2**	**22.5**	**32,297**	....	**53,401**	**94,255**	**60.6**

This iron was manufactured from selected contract chain-iron mixed with old boiler-iron. Test-pieces were swaged from the blooms and tested by tension and impact cell of the blooms, which passed satisfactory tests, was rolled into iron A or experimental cable-iron.

Tension tests upon round bars of hammered iron—Continued.

Investigation—Character of the core of the swaged bars Nos. 66 to 75. *Test-pieces*—Turned cylinders. *Testing-machine*—B.

Iron—HAMMERED (blooms from which iron A was rolled).

Test number.	Dimensions of test-pieces.						Stress in pounds at—				Ratio of elastic to tensile limit.
	Diameter.		Length.		At fracture.		Elastic limit per square inch.	Tensile limit.			
	Original.	At fracture.	Original.	At fracture.	Reduced area.	Per cent. of elongation.		Observed.	Per square inch original area.	Per square inch fractured area.	
	"	"	"	"							
95	.980	.736	4.06	5.32	54.3	31.0	26,027	38,400	48,992	90,502	53.8
96	.992	.725	3.90	5.20	53.4	33.3	25,617	36,700	47,483	88,905	74.1
97	.987	.760	3.93	5.02	59.3	27.8	34,374	39,300	51,365	86,640	66.2
98	.974	.775	3.89	4.95	63.3	27.2	32,210	38,050	50,066	80,665	63.9
99	.974	.775	3.89	4.98	63.3	28.0	30,197	38,600	51,805	81,331	58.0
100	.565	.447	2.26	2.79	62.6	23.5	33,805	12,690	50,618	80,879	67.3
101	.565	.505	2.26	2.51	*79.9	*11.0	36,896	13,120	52,333	*65,502	70.0
102	.565	.453	2.28	2.88	64.3	26.3	34,623	12,950	51,655	80,335	66.1
103	.565	......	2.28	......	......	......	33,306	12,325	49,162	......	......
104	.565	.429	2.28	2.97	57.5	30.0	34,942	13,000	51,854	89,965	67.4
105	.565	.430	2.28	2.97	57.9	30.0	35,600	13,125	52,353	90,392	68.0
106	.566	.452	2.29	2.90	63.8	26.6	39,546	12,900	51,271	80,873	77.1
107	.567	.440	2.29	2.91	60.2	27.0	39,306	13,125	51,980	86,348	75.6
108	.567	.425	2.22	2.82	56.2	27.0	31,683	12,500	49,505	88,090	64.0
109	.567	.408	2.30	3.02	51.8	23.8	32,871	12,725	50,396	97,360	65.2
110	.567	.447	2.25	2.87	62.1	27.8	36,831	13,000	51,486	82,555	71.5
111	.562	.469	2.25	2.72	60.6	20.9	38,291	12,450	50,181	72,048	76.3
Av.	......	......	......	......	59.9	27.1	33,948	......	50,735	85,090	67.7

Figures marked * are not considered in averages.

Tension tests upon round bars of rolled iron.

Investigation—Daily tests of experimental cable iron. *Test-pieces*—Bars as rolled and cylinders. *Testing-machines*—A and B.

IRON A.

Test number.	Dimensions of test-pieces.						Stress in pounds at—				Ratio of elastic to tensile limit.	Strength per square inch of bloom from which ore was rolled.
	Diameter.		Length.		At fracture.		Elastic limit per square inch.	Tensile limit.				
	Original.	At fracture.	Original.	At fracture.	Original.	At fracture.		Observed.	Per square inch original area.	Per square inch fractured area.		
	"	"	"	"								
112	2.00	1.48	7.00	8.61	55.0	23.0	31,786	172,800	55,014	100,465	57.7	....
113	2.00	1.66	8.00	9.66	69.0	21.0	27,507	155,990	49,662	72,084	55.4	....
114	2.00	1.65	8.00	9.71	68.0	21.0	27,627	160,800	51,193	75,210	54.0	....
115	2.00	1.49	9.00	11.50	56.0	28.0	28,118	155,040	49,860	88,899	57.0	....
116	2.00	1.51	11.00	13.68	57.0	24.0	28,729	159,552	50,796	89.134	56.6	....
*117	2.00	1.83	11.00	12.70	*84.0	*15.0	27,507	153,120	48.748	*58,220	56.4	....
*118	2.00	1.90	11.00	11.82	*90.0	*08.0	30,869	144,480	45,998	*50,963	67.1	....
119	2.00	1.48	11.00	13.67	55.0	24.0	29,353	162,720	51,805	94,604	56.7	....
120	2.00	1.54	11.00	13.62	59.0	24.0	....	153,792	48,962	82,550	60.0	....
Av...	......	......	......	......	59.9	23.6	28,854	160,099	50,790	86,185	57.8	....

Tension tests upon round bars of rolled iron—Continued.

IRON A—Continued.

Test number.	Dimensions of test-pieces.						Stress in pounds at—				Ratio of elastic to tensile limit.	Test number of bloom.
	Diameter.		Length.		At fracture.		Elastic limit per square inch.	Tensile limit.				
	Original.	At fracture.	Original.	At fracture.	Original.	Per cent. of elongation.		Observed.	Per square inch original area.	Per square inch fractured area.		
	"	"	"	"								
121	.978	.796	3.91	4.97	66.3	27.1	28,620	38,690	51,502	77,747	55.5	100
122	.978	.708	3.91	5.21	52.5	33.0	27,954	36,500	48,587	92,712	57.5	101
123	.998	.781	4.00	5.08	61.3	26.0	31,958	40,600	51,901	84,749	61.4	106
124	.997	.877	4.00	4.72	77.4	18.0	33,177	39,200	50,217	64,893	66.6	107
125	.999	.756	4.00	5.31	57.3	32.8	32,597	40,150	51,225	89,445	63.6	108
126	1.000	.740	4.00	5.18	54.7	29.5	30,812	39,320	50,064	91,424	61.1	109
127	1.000	.749	4.00	5.23	56.0	30.7	26,738	38,820	49,424	88,105	54.0	110
128	1.000	.758	4.01	5.16	57.3	28.6	26,738	39,220	49,436	86,912	53.5	111
129	1.000	.779	4.02	4.98	60.7	23.9	30,557	39,190	49,898	82,226	61.2	102
130	1.000	.718	3.99	5.19	51.6	30.0	29,603	38,250	48,701	94,470	60.8	103
131	1.000	.770	3.99	5.23	59.3	31.1	30,049	39,125	49,816	84,021	60.3	104
132	1.000	.696	3.99	5.21	48.5	31.0	29,539	39,420	50,191	103,611	58.8	105
133	1.000	.780	3.99	5.16	60.9	29.1	31,691	38,850	49,465	81,305	64.1	95
134	1.000	.709	3.99	5.36	50.3	34.4	25,464	36,510	46,486	92,477	54.7	96
135	1.000	.715	3.99	5.34	51.2	33.8	25,460	36,700	46,728	91,404	54.5	97
136	.975	.728	3.90	4.96	55.8	27.2	33,852	38,380	51,405	92,206	65.8	98
137	.975	.738	3.90	4.60	57.3	17.9	25,448	34,180	45,779	80,187	55.6	99
138	.975	.704	3.90	5.32	52.2	36.4	26,204	36,800	49,289	94,541	53.2	....
Av...	.993	.750	3.97	5.12	57.2	29.0	29,247	38,439	49,480	87,355	59.0	....

The above tests give but the minimum value of the experimental cable iron, inasmuch as our process of manufacture was so slow, and facilities so limited, that we could afford to test only such bars as through defect of fire-crack, &c., were considered unsuitable for the cable.

Tests Nos. 112 to 120 were upon entire bars, by machine A; the remainder upon cylinders turned from the bars which were rolled from the blooms, the tension tests of which are numbered 95 to 111.

Figures marked * are not considered in averages.

Investigation—Production of valuable chain-iron from combination of assorted scrap-iron, and effect of reduction by the rolls to various diameters. *Test-pieces*—Bars as rolled. *Testing-machine*—A.

IRON A (EXPERIMENTAL CABLE).

Test number.	Approximate diameter of bar.	Dimensions of test-pieces.						Stress in pounds at—				Ratio of elastic to tensile limit.
		Diameter.		Length.		At fracture.		Elastic limit per square inch.	Tensile limit.			
		Original.	At fracture.	Original.	At fracture.	Reduced area.	Per cent. of elongation.		Observed.	Per square inch original area.	Per square inch fractured area.	
	"	"	"	"	"							
139	1	1.02	.70	6.0	7.25	47.0	21.0	35,124	45,120	55,218	127,255	63.6
140	"	1.02	.69	6.0	7.50	46.0	25.0	34,071	45,500	55,683	121,700	61.2
141	"	1.00	.69	5.5	6.71	46.0	22.0	35,448	41,760	53,170	111,687	66.6
Av.	......	....	....	....	....	46.3	22.7	34,881	44,126	54,690	120,214	63.8
142	1⅛	1.13	.77	7.0	8.49	46.4	21.0	25,789	54,144	54,050	116,288	49.5
143	"	1.13	.78	7.0	8.71	47.6	24.4	26,249	53,952	53,860	112,917	50.5
144	"	1.13	.76	5.5	6.95	45.2	25.0	28,324	53,896	53,790	116,611	53.7
Av.	......	....	....	....	....	46.4	23.5	26,787	53,997	53,900	115,272	51.2

Tension tests upon round bars of rolled iron—Continued.

IRON A (EXPERIMENTAL CABLE)—Continued.

Test number.	Approximate diameter of bar.	Dimensions of test-pieces.						Stress in pounds at—				Ratio of elastic to tensile limit.
		Diameter.		Length.		At fracture.		Elastic limit per square inch.	Tensile limit.			
		Original.	At fracture.	Original.	At fracture.	Reduced area.	Per cent. of elongation.		Observed.	Per square inch original area.	Per square inch fractured area.	
	"	"	"	"	"							
145	1¼	1.25	.87	7.0	8.76	48.5	25.0	25,036	65,856	53,670	110,775	46.6
146	"	1.25	.88	7.0	8.73	48.5	24.7	26,118	66,816	54,451	109,858	48.7
147	"	1.25	.86	5.5	7.10	44.4	29.0	31,295	65,664	53,515	113,038	58.5
Av.	......	......	......	......	......	48.1	26.2	27,483	66,112	53,879	111,227	51.3
148	1⅜	1.37	.96	7.0	8.70	49.0	24.3	33,215	78,432	53,210	106,861	62.4
149	"	1.37	.95	7.0	8.74	48.0	25.0	33,867	78,624	53,340	110,925	63.5
150	"	1.37	.93	7.0	8.78	46.0	25.4	33,800	79,776	54,122	117,438	62.5
Av.	......	......	......	......	......	47.7	24.9	33,650	78,944	53,557	112,241	62.8
151	1½	1.50	1.02	7.0	8.71	46.3	24.4	28,794	90,624	51,286	110,909	56.1
152	"	1.50	1.02	7.0	8.85	46.3	26.4	28,800	92,736	52,482	118,494	54.8
Av.	......	......	......	......	......	46.3	25.4	28,797	91,680	51,884	112,201	55.4
154	1⅝	1.62	1.24	11.0	13.11	59.0	19.0	32,605	111,744	54,218	92,503	60.2
155	"	1.62	1.16	9.0	10.75	50.5	19.0	31,722	112,224	54,451	106,172	58.2
Av.	......	......	......	......	......	54.7	19.0	32,163	111,984	54,334	99,338	59.1
156	1¾	1.74	1.26	11.0	13.28	52.5	20.7	29,718	123,744	52,058	99,233	57.0
157	"	1.76	1.25	9.0	11.12	50.5	23.6	29,210	123,936	50,960	100,007	57.3
Av.	......	......	......	......	......	51.5	22.1	29,464	123,840	51,509	99,620	57.2
158	1⅞	1.88	1.35	12.0	14.51	52.0	21.0	29,741	142,080	51,200	99,287	58.0
159	"	1.88	1.37	12.0	14.80	53.0	23.5	27,765	140,160	50,508	95,088	54.0
Av.	......	......	......	......	......	52.5	22.2	28,713	141,120	50,854	97,187	56.0
160	2	2.01	1.50	12.0	14.37	56.0	19.7	30,709	163,200	51,402	92,859	59.7
161	"	2.01	1.46	12.0	14.80	53.0	23.5	30,225	161,280	50,828	96,844	59.5
Av.	......	......	......	......	......	54.5	21.5	30,467	162,240	51,115	94,851	59.6
162	2⅛	2.12	1.62	12.0	14.05	58.0	17.0	30,459	170,784	48,382	82,864	63.0

The tests Nos. 139 to 162, inclusive, were made upon bars of the experimental cable iron manufactured on the 27th of February, 1875, which for experimental purposes were rolled to the sizes indicated. The tests of chain links made from these bars are given on page 177, and on Plates VII and VIII is shown the action of the iron when submitted to tests for ductility: the 1" having been tied into an overhand knot, the 1½" cut into a screw and bent double cold by impact, and the 2⅛-inch bar having been bent double cold in two directions. For strength and uniformity as chain cable, the bars ranked No. 2 in competitive test with 16 irons; in resistance to shock, No. 1 (see page 225).

Tension tests upon round bars of rolled iron—Continued.

Investigation—Character of iron as adapted for chain cables. Competitive test of irons B, C, E, H, I, J, L, and M, May, 1874. *Test-pieces*—bars as rolled and grooved cylinders. *Testing-machines*—A and B.

IRON B.

Test number.	Diameter of bar.	Dimensions of test-pieces.						Stress in pounds at—				Ratio of elastic to tensile limit.
		Diameter.		Length.		At fracture.		Elastic limit per square inch.	Tensile limit.			
		Original.	At fracture.	Original.	At fracture.	Reduced area.	Per cent. of elongation.		Observed.	Per square inch original area.	Per square inch fractured area.	
	"	"	"	"	"							
163	1 7/16	1 7/16........	1⅛	27.0	31.3	61.3	15.9	....	89,090	54,892	89,627	......
164 to 166	"	½ sq. inch.	......	......	......	......	......	....	....	54,778	....	......
167	1 11/16	1 11/16........	1¼	27.0	31.0	54.9	15.0	....	121,150	54,181	98,736	......
168 to 170	"	¾ sq. inch.	......	......	......	......	......	....	....	53,183	....	......
171	1 13/16	1 13/16........	1 7/16	27.0	31.5	62.9	16.6	....	142,660	55,294	87,892	......
172 to 174	"	¾ sq. inch.	......	......	......	......	......	....	....	53,217	....	......
IRON C.												
175	1 7/16	....	1 1/16	27.0	31⅜	54.6	16.2	32,655	84,000	51,756	94,808	63.1
176	1½	....	1 3/16	27.0	30⅞	62.7	13.0	35,880	98,100	52,700	84,101	63.6
177	1⅝	....	1 3/16	27.0	31¼	53.4	15.7	31,099	101,700	49,030	91,870	63.4
178	1 11/16	....	1 7/16	27.0	31½	67.5	15.7	30,852	121,000	50,312	74,558	61.3
179	1¾	....	1 3/16	27.0	31.0	60.5	15.0	33,184	111,400	49,821	84,552	66.6
180	1 13/16	....	1⅜	27.0	30¾	57.5	13.9	30,814	131,500	50,969	88,552	60.2
IRON E.												
181	1 7/16	1 7/16........	1	27.0	30.3	48.0	13.9	32,542	87,552	53,994	....	60.3
182 to 184	"	½ sq. inch.	......	......	......	......	......	....	....	51,936	....	......
185	1½	1½.........	1⅛	27.0	30.5	56.3	14.4	33,027	96,384	54,544	....	60.6
186 to 188	"	½ sq. inch.	......	......	......	......	......	....	....	51,200	....	......
189	1⅝	1⅝.........	1 3/16	27.0	30⅞	53.4	13.0	33,745	109,248	52,675	....	64.6
190 to 192	"	½ sq. inch.	......	......	......	......	......	....	....	52,800	....	......
193	1 11/16	1 11/16........	1 3/16	27.0	30.0	60.5	11.1	33,549	116,541	52,120	....	62.7
194 to 196	"	¾ sq. inch.	......	......	......	......	......	....	....	53,000	....	......
197	1¾	1¾.........	1¼	27.0	31¼	51.0	15.7	31,214	119,808	49,816	....	62.7
198 to 200	"	....	......	......	......	......	......	....	....	50,320	....	......
201	1 13/16	1 13/16........	1 3/16	27.0	31.0	52.4	14.8	29,767	129,792	50,807	....	59.2
202 to 204	"	¾ sq. inch.	......	......	......	......	......	....	....	49,950	....	......

Tension tests upon round bars of rolled iron—Continued.

Investigation—Character as adapted for chain cables. Competitive test on eight irons. *Test-pieces*—Bars as rolled and grooved cylinders. *Testing-machines*—A and B.

IRON G.

Test number.	Diameter of bar.	Dimensions of test-pieces.						Stress in pounds at—				Ratio of elastic to tensile limit.
		Diameter.		Length.		At fracture.		Elastic limit per square inch.	Tensile limit.			
		Original.	At fracture.	Original.	At fracture.	Reduced area.	Per cent. of elongation.		Observed.	Per square inch original area.	Per square inch fractured area.	
	″	″	″	″	″							
205	1 7/16	1 7/16........	1⅛	27.0	31⅛	61.3	15.3	32,584	86,400	53,238	86,921	61.1
206 to 208	"	½ sq. inch.	......	......	......	......	......	....	....	52,067	....	......
209	1½	1½........	1⅛	27.0	31	56.3	14.8	35,425	91,800	51,958	92,354	68.1
210 to 212	"	½ sq. inch.	......	......	......	......	......	....	....	55,167	....	......
213	1⅝	1⅝........	1⅜	27.0	30⅛	71.6	11.6	33,818	106,200	51,205	71,524	65.6
214 to 216	"	½ sq. inch.	......	......	......	......	......	....	....	54,960	....	......
217	1 11/16	1 11/16........	1 5/16	27.0	30½	60.5	13.0	34,160	115,800	51,789	85,593	66.0
218 to 220		½ sq. inch.	......	......	......	......	......	....	....	51,267	....	......
221	1¾	1¾........	1½	27.0	30¼	73.5	12.0	36,254	121,200	50,395	68,587	72.0
222 to 224	"	½ sq. inch.	......	......	......	......	......	....	....	51,267	....	......
225	1 13/16	1 13/16........	1 7/16	27.0	30½	62.9	13.0	33,565	129,800	50,310	79,980	66.7
226 to 228	"	½ sq. inch.	......	......	......	......	......	....	....	50,850	....	......

IRON H.

Test number.	Diameter of bar.	Original.	At fracture.	Original.	At fracture.	Reduced area.	Per cent. of elongation.	Elastic limit per square inch.	Observed.	Per square inch original area.	Per square inch fractured area.	Ratio of elastic to tensile limit.
229	1½	1½........	1 3/16	27.0	29½	62.7	9.3	29,992	92,700	52,462	83,702	57.1
230 to 232	"	½ sq. inch.	......	......	......	......	......	....	....	53,800	....	......
233	1⅝	1⅝........	1¼	27.0	31¼	59.2	15.7	29,364	108,500	52,314	88,419	56.1
234 to 236	"	½ sq. inch.	......	......	......	......	......	....	....	52,167	....	......
237	1¾	1¾........	1 9/16	27.0	30	79.7	11.1	27,856	129,400	53,800	67,485	51.7
238 to 240	"	½ sq. inch.	......	......	......	......	......	....	....	51,217	....	......

IRON I.

Test number.	Diameter of bar.	Original.	At fracture.	Original.	At fracture.	Reduced area.	Per cent. of elongation.	Elastic limit per square inch.	Observed.	Per square inch original area.	Per square inch fractured area.	Ratio of elastic to tensile limit.
241	1½	....	......	27.0	27⅛	......	......	....	78,800	44,500	....	......
242	1⅝	....	......	27.0	......	......	......	....	....	....	....	......
243	1¾	....	......	......	......	......	......	....	....	....	....	......
244 to 247	......	....	......	......	......	......	......	....	....	58,655	....	......
248 to 251	......	....	......	......	......	......	......	....	....	52,575	....	......
252 to 255	......	....	......	......	......	......	......	....	....	50,687	....	......

241 broke at weld at very slight stress, iron very red-short and worthless; 242 and 243 broke while welding on loops, and were not tested.

Tension tests upon round bars of rolled iron—Continued.

IRON J.

Test number.	Diameter of bar.	Dimensions of test-pieces.						Stress in pounds at—				Ratio of elastic to tensile limit.
		Diameter.		Length.		At fracture.		Elastic limit per square inch.	Tensile limit.			
		Original.	At fracture.	Original.	At fracture.	Reduced area.	Per cent. of elongation.		Observed.	Per square inch original area.	Per square inch fractured area.	
		"	"	"	"							
256	1 7/16	1 7/16........	1¼	27.0	30¼	75.6	12.0	....	81,800	50,400	66,666	......
257 to 259	"	½ sq. inch.	......	......	......	......	......	....	....	47,067	....	......
260	1½	1½........	1⅛	27.0	30¾	56.3	14.0	....	90,200	51,047	90,744	......
261 to 263	1½	½ sq. inch.	......	......	......	......	......	....	....	51,867	....	......
264	1⅝	1⅝........	1⅜	27.0	29½	71.6	9.3	....	109,400	52,748	73,670	......
265 to 267	....	....	......	......	......	......	......	....	....	50,367	....	......
268	1 11/16	1 11/16........	1⅜	27.0	31.0	66.4	14.8	....	121,000	54,114	81,481	......
269 to 271	"	½ sq. inch.	......	......	......	......	......	....	....	51,783	....	......
272	1¾	1¾........	1 9/16	27.0	30⅛	79.7	11.6	....	128,000	53,264	66,823	......
273 to 276	"	½ sq. inch.	......	......	......	......	......	....	....	51,750	....	......
277	1 13/16	1 13/16........	1½	27.0	30¾	68.5	14.0	....	126,300	48,953	71,477	......
278 to 281	"	½ sq. inch.	......	......	......	......	......	....	....	48,800	....	......

The fractured surface of this iron presented a resemblance to charcoal, very inferior, and called by the blacksmith "rotten."

IRON L.

282	1 7/16	1 7/16........	......	27.0	29½	......	......	32,162	112,230	69,205	....	46.4
283 to 285	"	½ sq. inch.	......	......	......	......	......	....	....	66,167	....	......
286	1½	1½........	......	27,0	28¾	......	......	28,579	123,300	69,779	....	40.9
287 to 289	"	½ sq. inch.	......	......	......	......	......	....	18,792	75,167	....	......
290	1⅝	1⅝........	1 5/16	27.0	28¾	......	......	44,792	139,200	67,116	102,882	66.7
291 to 293	"	½ sq. inch.	......	......	......	......	......	....	19,767	79,067	....	......
294	1 11/16	1 11/16........	1 3/16	27.0	31½	......	......	32,933	123,700	55,822	111,748	59.0
295 to 297	"	½ sq. inch.	......	......	......	......	......	....	14,067	56,267	....	......
298	1¾	1¾........	1¼	27.0	30	......	......	36,257	145,000	60,291	118,774	60.1
299 to 301	"	½ sq. inch.	......	......	......	......	......	....	29,350	58,700	....	......
302	1 13/16	1 13/16........	1 5/16	27.0	31¼	......	......	34,961	145,000	56,200	107,169	62.2
303 to 305	"	½ sq. inch.	......	......	......	......	......	....	29,800	59,600	....	......

The physical tests indicated that this material, sent in to compete with chain iron, was steel, the grain being fine and silvery, taper at fracture very abrupt, and welding power low. Chemical analysis confirmed the results of physical tests. As this is the only material which came up to the government standard of 60,000 lbs. tensile strength, its results as chain are interesting and valuable.

Tension tests upon round bars of rolled iron—Continued.

IRON M.

Test number.	Diameter of bar.	Dimensions of test-pieces.						Stress in pounds at—				Ratio of elastic to tensile limit.
		Diameter.		Length.		At fracture.		Elastic limit, per square inch.	Tensile limit.			
		Original.	At fracture.	Original.	At fracture.	Reduced area.	Per cent. of elongation.		Observed.	Per square inch original area.	Per square inch fractured area.	
	"	"	"	"	"							
306	1½	1½........	......	27.0	......	......	......	....	87,100	....	....	......
307	1⅝	1⅝........	......	27.0	......	......	......	....	95,600	....	....	......
308	1¾	1¾........	......	27.0	......	......	......	....	92,200	....	....	......
309 to 311	1½	½ sq. inch.	......	......	......	......	......	....	....	55,267	....	......
312 to 314	1⅝	½ sq. inch.	......	......	......	......	......	....	....	57,267	....	......
315	1¾	....	......	......	......	......	......	....	....	51,330	....	......

All the bars broke at weld with low strain, iron red-short, and worthless. It may or may not be the same iron as that of which a large quantity was subsequently received by the department, and whose record is given under same symbol, M.

The same contractor furnished both, and states them to be the same.

Investigation—Character of iron as adapted for chain cables. *Test-pieces*—Bars as rolled and turned cylinders. *Testing-machine*—A.

IRON B.

[Chain bolts delivered and claimed to be of same iron as samples Nos. 163 to 174 inclusive.]

Test number.	Diameter of bar.	Dimensions of test-pieces.						Stress in pounds at—				Ratio of elastic to tensile limit.
		Diameter.		Length.		At fracture.		Elastic limit, per square inch.	Tensile limit.			
		Original.	At fracture.	Original.	At fracture.	Reduced area.	Per cent. of elongation.		Observed.	Per square inch original area.	Per square inch fractured area.	
	"	"	"	"								
316	1$\frac{7}{16}$	1$\frac{7}{16}$	1$\frac{5}{16}$	12.00	13.25	83.4	10.4	31,233	83,710	51,577	61,870	60.5
317	"	"	1$\frac{3}{16}$	12.00	14.00	68.3	16.6	35,490	86,400	53,234	78,040	66.6
318	"	"	1⅛	18.00	21.5	64.2	19.4	33,358	84,860	52,285	85,872	63.8
319	"	"	1¼	18.00	....	75.6	....	29,575	84,480	52,051	68,850	56.8
Av.	......	......	......	......	....	72.9	15.5	32,414	84,862	52,287	73,583	61.9
163	......	......	......	......	....	61.3	15.7	....	89,090	54,892	89,627	.....
320	1$\frac{11}{16}$	1$\frac{11}{16}$	1⅜	18.00	21.87	66.4	18.7	33,488	120,960	54,096	82,814	61.9
321	"	"	1⅜	18.00	20.40	66.4	13.1	32,630	116,930	52,294	78,740	62.4
322	"	"	1$\frac{5}{16}$	18.00	21.12	60.5	17.3	33,318	116,930	52,294	87,422	63.7
Av.	......	......	......	......	....	64.4	16.4	33,145	118,273	52,895	86,325	62.7
167	......	......	......	......	....	54.9	15.0	....	121,150	54,181	98,736	.....
323	1$\frac{13}{16}$	1$\frac{13}{16}$	1⅜	18.00	21.87	57.6	18.7	34,159	139,470	53,282	92,572	61.1
324	"	"	1⅜	18.00	21.75	57.6	20.8	32,596	136,130	52,763	91,670	61.7
325	"	"	1⅜	18.00	21.87	57.6	21.5	35,271	137,470	53,282	92,572	66.1
Av.	......	......	......	......	....	57.6	20.3	34,009	137,023	53,109	92,271	63.0
171	......	......	......	......	....	62.9	16.6	....	142,660	55,294	87,892	.....

Tension tests upon round bars of rolled iron—Continued.

Testing-machine—B.

IRON B—Continued.

Test number.	Diameter of bar.	Dimensions of test-pieces.						Stress in pounds at—				Ratio of elastic to tensile limit.
		Diameter.		Length.		At fracture.		Elastic limit per square inch.	Tensile limit.			
		Original.	At fracture.	Original.	At fracture.	Reduced area.	Per cent. of elongation.		Observed.	Per square inch original area.	Per square inch fractured area.	
	″	″	″	″	″							
326 327	$1\frac{7}{16}$	.565	.505	1.30	1.53	80.0	18.0	......	......	48,863	......	......
328 329	"	.565	.470	1.30	1.64	69.5	26.2	......	......	49,512	......	......
330 331	"	.565	.425	1.30	1.75	56.7	34.3	......	......	50,458	......	......
332 333	"	.565	.442	1.30	1.72	61.4	32.7	......	......	52,271	......	......
334 335	"	.565	.440	1.30	1.69	60.3	30.7	......	......	50,106	......	......
Av.	......	......	......	......	......	65.6	28.4	......	......	50,221	......	......
*...	......	......	......	......	Gr've	......	......	......	......	54,773	......	......
336 337	$1\frac{11}{16}$	.800	.630	1.30	1.73	62.2	33.5	......	......	51,228	......	......
338 339	"	.800	.645	1.30	1.72	65.0	32.7	......	......	51,000	......	......
340 341	"	.800	.627	1.30	1.75	61.5	34.6	......	......	50,925	......	......
342 343	"	.800	.637	1.30	1.73	63.5	33.6	......	......	50,228	......	......
Av.	......	......	......	......	......	63.1	33.8	......	......	50,844	......	......
*...	......	......	......	......	Gr've	62.9	16.6	......	......	53,183	......	......
344 345	$1\frac{13}{16}$	.800	.610	1.30	1.74	60.0	33.2	......	......	49,880	......	......
346 347	"	.800	.608	1.30	1.75	57.6	35.6	......	......	49,350	......	......
348 349	"	.800	.613	1.30	1.78	58.8	37.5	......	......	49,200	......	......
350 to 352	"	.800	.610	1.30	1.79	60.0	38.1	......	......	50,162	......	......
Av.	......	......	......	......	......	59.1	36.1	......	......	49,709	......	......
*...	......	......	......	......	Gr've	62.9	16.6	......	......	52,217	......	......

The tests marked * are those of the sample bars, reproduced for ready comparison, made upon the grooved-shaped test-pieces they show, by comparison with the results obtained by cylindrical test-pieces (which were still too short for accuracy) the errors arising from use of the hourglass or grooved test-pieces.

Tension tests upon round bars of rolled iron—Continued.

Investigation—Character of iron as adapted for chain-cables. *Test-pieces*—Bars as rolled. *Testing-machine*—A.

IRON C.

[Chain bolts delivered.]

Test number.	Dimensions of test-pieces.						Stress in pounds at—				Ratio of elastic to tensile limit.
	Diameter.		Length.		At fracture.		Elastic limit per square inch.	Tensile limit.			
	Original.	At fracture.	Original.	At fracture.	Reduced area.	Per cent. of elongation.		Observed.	Per square inch original area.	Per square inch fractured area.	
	"	"	"	"							
353	1½	1 3/16	17.0	20¾	62.7	22.0	29,881	98,880	55,956	89,322	58.4
354	"	1 3/16	15.5	18½	62.7	19.8	....	95,040	53,726	85,853	.....
355	"	....	....	....	62.7	....	35,857	97,926	55,419	88,460	64.7
356	"	1⅛	....	....	56.3	....	37,487	100,800	57,045	101,408	65.7
357	"	1 3/16	....	....	62.7	....	35,857	96,960	54,872	87,588	65.8
Av.	....	....	....	....	....	....	34,770	97,921	55,404	90,526	62.9
*...	....	....	....	....	....	....	35,880	98,100	52,700	84,101	68.6
358	1⅝	1 3/16	19.5	22⅝	58.4	18.5	33,809	116,160	56,010	104,923	63.4
359	"	1 3/16	19.5	22¼	53.4	20.5	32,402	117,120	56,473	105,799	57.3
360	"	1 3/16	....	....	53.4	....	31,939	112,320	54,158	101,463	62.0
361	"	1¼	....	....	59.2	....	35,180	117,396	56,878	95,921	63.4
Av.	....	....	....	....	....	....	33,207	115,749	55,879	102,026	61.7
*...	....	....	....	....	....	....	31,099	101,700	49,030	91,870	63.4
362	1¾	1 7/16	20.0	23¾	67.5	18.7	31,531	129,600	53,883	79,852	61.3
363	"	1⅜	12.0	140	61.8	16.7	32,829	130,360	54,282	87,935	59.5
364	"	1 5/16	12.0	140	52.7	16.7	31,930	134,400	55,873	99,834	57.1
365	"	1 7/16	10.0	11⅞	67.5	18.7	31,057	130,600	54,290	80,468	55.1
366	"	1 7/16	20.0	23¼	....	16.1	29,935	129,716	53,723	79,615	59.5
Av.	....	....	....	....	....	....	31,356	130,835	54,410	85,441	57.3
*...	....	....	....	....	....	....	30,852	121,000	50,312	88,552	61.3

Tests marked * are those of the original sample bars—the remainder, of iron delivered to fill contract which this iron gained on these sizes in the competitive test. It will be noticed by study of the record as chain links that the sample bars of low tensile strength, produced by far the strongest and most uniform chain links. Thus,

1½	inch	sample link,	178,200	pounds,	iron delivered	169,264	pounds.
1⅝	"	"	192,000	"	"	192,685	"
1¾	"	"	241,000	"	"	230,000	"

IRON C.

[Bars purchased for testing purposes.]

Test number.	Diameter of bar.	Diameter of test-pieces.						Stress in pounds at—				Ratio of elastic to tensile limit.
		Diameter.		Length.		At fracture.		Elastic limit per square inch.	Tensile limit.			
		Original.	At fracture.	Original.	At fracture.	Reduced area.	Per cent. of elongation.		Observed.	Per square inch original area.	Per square inch fractured area.	
	"	"	"	"	"							
367	1⅛	1⅛	⅞	11	13¼	60.5	20.4	30,000	56,650	56,992	94,191	52.6
368	"	1⅛	⅞	11	12⅞	60.5	17.0	33,802	57,600	57,948	95,742	58.3
Av.	....	....	....	....	....	....	....	31,901	57,125	57,470	94,966	55.4
369	1¼	1¼	1	14	16¾	64.1	19.6	32,469	71,040	57,897	90,450	56.0
370	1⅜	1⅜	1⅛	18	21⅛	67.0	11.7	31,084	81,600	54,940	82,093	56.4
371	1⅞	1⅞	1½	21	25	64.0	17.0	32,334	150,836	54,447	85,071	59.3
372	2	2	1¾	21	24	76.6	14.3	29,335	160,704	51,153	66,815	57.3

This set of bars was purchased in order to obtain the record of strength of all sizes of the iron as bars and links; also, for a series of comparative tests of bars with and without the skin.

Tension tests upon round bars of rolled iron—Continued.

Investigation—Comparison of strength of rough and turned bars. *Test-pieces*—Rough and turned cylinders. *Testing-machine*—B.

IRON C.

[Bar purchased for testing purposes.]

Test number.	Bar.		Dimensions of test-pieces.						Stress in pounds at tensile limit.		
			Diameter.		Length.		At fracture.				
	Diameter.	Rough or turned.	Original.	At fracture.	Original.	At fracture.	Reduced area.	Per cent. of elongation.	Per square inch.	Rough exceeds turned.	Turned exceeds rough.
	″		″	″	″	″					
373	1⅛	R	1.146	.840	5.07	....	53.5	36.9	53,387	....	....
374	"	R	1.145	.850	4.65	....	55.0	22.6	53,073	....	....
375	"	R	1.140	.855	4.15	....	56.2	33.1	52,899	....	....
376	"	R	1.150	.864	4.18	....	56.5	26.5	52,436	....	....
Av.	......	......	....	....	....	....	55.4	29.7	52,949	....	....
377	1⅛	T	.965	.730	3.67	....	57.3	27.2	52,228	....	....
378	"	T	.975	.707	4.15	....	52.6	27.1	52,805	....	....
379	"	T	.977	.763	3.45	....	61.0	25.3	53,354	....	....
Av.	......	......	....	....	....	....	57.0	26.5	52,796	153	....
380	1	R	1.024	.752	3.80	....	54.0	22.3	53,424	....	....
381	"	R	1.024	.779	3.70	....	57.9	24.3	54,644	....	....
382	"	R	1.024	.760	3.40	....	56.0	23.3	54,159	....	....
Av.	......	......	....	....	....	....	56.0	23.3	54,076	....	....
383	1	T	.955	.692	3.97	....	52.5	30.8	53,120	....	....
384	"	T	.950	.690	4.00	....	52.8	31.2	53,582	....	....
385	"	T	.956	.695	4.07	....	52.9	30.6	53,070	....	....
386	"	T	.960	.692	4.07	....	52.0	30.6	52,640	....	....
Av.	......	......	....	....	....	....	52.5	30.8	53,103	973	....
387	½	R	.525	.399	2.72	....	55.2	53.0	59,066	....	....
388	"	R	.523	.386	2.87	....	51.5	53.0	57,216	....	....
389	"	R	.525	.393	2.90	....	56.1	35.0	60,789	....	....
390	"	R	.512	.372	2.90	....	52.8	57.0	60,082	....	....
391	"	R	.525	.375	2.92	....	51.0	45.0	55,428	....	....
Av.	......	......	....	....	....	....	53.3	48.6	58,496	....	....
393	½	T	.400	.295	2.00	....	54.4	42.0	64,837	....	....
394	"	T	.400	.285	2.15	....	50.8	55.0	62,649	....	....
395	"	T	.400	.280	2.15	....	49.8	57.0	64,431	....	....
396	"	T	.400	.280	2.15	....	49.8	45.0	60,461	....	....
397	"	T	.400	.295	2.15	....	54.4	47.0	63,246	....	....
398	"	T	.400	.283	2.15	....	58.0	50.0	61,257	....	....
Av.	......	......	....	....	....	....	52.9	49.3	62,813	....	4,317
399	½	R	.523	.400	2.10	....	58.5	18.7	55,400	....	....
400	"	R	.505	.388	2.00	....	40.8	21.2	56,540	....	....
401	"	R	.520	.406	2.65	....	61.0	16.0	55,555	....	....
402	"	R	.520	.421	2.47	....	65.6	20.2	55,791	....	....
403	"	R	.520	.444	2.45	....	72.9	16.3	54,849	....	....
404	"	R	.512	.387	2.45	....	57.1	21.2	56,216	....	....
Av.	......	......	....	....	....	....	59.3	18.9	55,725	....	....
405	½	T	.400	.305	1.99	....	58.2	24.6	49,920	....	....
406	"	T	.381	.320	2.25	....	60.9	25.3	58,333	....	....
407	"	T	.400	.290	2.00	....	56.2	21.2	52,705	....	....
408	"	T	.400	.300	1.95	....	56.3	21.8	56,467	....	....
409	"	T	.389	.312	1.85	....	64.4	17.6	59,132	....	....
Av.	......	......	....	....	....	....	60.9	....	55,311	414	....

The results from the tests of the half-inch bars are not very reliable in the data of first stretch or of elongation, as the test-pieces were so slight. There is some reason to believe that the first turned set of half-inch test-pieces may have been prepared from iron K by mistake; otherwise, the series were for each comparison from the same bar.

Tension tests upon round bars of rolled iron—Continued.

Investigation—Character of iron as adapted for chain cables, and effect of varying reduction from pile to bar. *Test-pieces*—Bars as rolled. *Testing-machine*—A.

IRON D.

[Two lots purchased for test purposes.]

Bar.		Dimensions of test-pieces.						Stress in pounds at—					Ratio of elastic to tensile limit.
		Diameter.		Length.		At fracture.		Elastic limit.		Tensile limit.			
Test number.	Diameter.	Original.	At fracture.	Original.	At fracture.	Reduced area.	Per cent. of elongation.	Observed.	Per square inch.	Observed.	Per square inch original area.	Per square inch fractured area.	
	″	″	″	″	″								
410	2	......	1.53	22.00	26.00	58.6	18.2	89,760	28,567	160,700	51,146	....	55.8
411	1⅞	......	1.42	22.00	26.50	57.4	20.0	76,800	27,816	142,080	51,459	....	54.0
412	1¾	......	1.22	20.00	24.20	48.7	21.2	66,900	27,817	126,720	52,699	....	52.8
413	1⅝	......	1.23	19.00	22.70	56.4	19.7	62,400	30,087	111,360	53,695	....	56.0
414	1½	......	1.13	18.00	21.40	56.8	18.9	48,960	27,708	92,160	52,155	....	53.1
415	1⅜	......	0.95	16.00	19.00	51.3	18.7	47,040	31,676	81,600	54,949	....	57.8
416	1¼	......	0.89	14.00	16.60	51.3	14.2	34,560	28,166	68,160	55,550	....	56.9
417	1⅛	......	0.72	10.00	12.00	41.5	19.8	29,300	29,476	54,360	54,687	....	53.9
418	2	1.98	1.96	9.00	9.10	97.9	......	....	....	142,100	46,151	47,100	....
419	1⅞	1.84	1.56	9.25	12.40	68.1	23.2	90,000	32,074	149,000	53,100	77,969	60.5
420	1¾	1.75	1.24	9.00	10.50	50.3	17.2	76,700	31,892	128,600	53,472	106,457	59.6
421	1⅝	1.62	1.20	9.00	10.45	54.9	16.1	63,200	30,664	110,500	53,614	97,701	57.2
422	1½	1.51	1.15	8.50	10.43	58.0	22.7	58,200	32,496	101,200	56,505	97,401	57.5
423	1⅜	1.38	1.03	7.55	9.61	55.7	24.0	47,500	32,152	86,800	58,021	104,176	54.7
424	1¼	1.26	0.94	7.00	8.23	55.7	17.6	39,900	31,996	72,300	57,979	104,178	55.2
425	1⅛	1.12	0.83	6.50	7.83	55.0	20.5	33,100	33,597	58,700	59,582	106,488	56.4
426	1	1.00	0.72	6.00	7.57	51.8	26.1	26,300	33,486	48,000	61,115	117,907	54.8
427													
428	2	1.97	1.89	10.00	10.75	98.0	07.5	99,800	33,068	149,800	49,146	53,386	66.6

The first set of bars of this iron were purchased in 1875, with the view of ascertaining the character of chain cable which a choice "rivet iron" would produce, and the second in 1877, for data in connection with the investigation of the effect of the rolls in reducing the piles to the various diameters.

The almost uninterrupted increase in proportionate strength which accompanied each successive reduction in diameter (interrupted only at 1¼″) indicates that the piles were of uniform areas for the sizes 1″, 1⅛″, 1¼″, and 1⅜″; and that at 1½″ the area of pile was changed, and remained uniform through the other increasing sizes. The first 2″ bar was very different in structure from the rest, and the fractures by tension and by impact closely resembled each other (Plate X). The areas adopted were for the medium sizes, well-suited for chain iron. For the larger sizes too little and for the smaller too much work was given. See record of chain links.

Tension tests upon round bars of rolled iron—Continued.

Investigation—Elevation of the limit of stress. *Test-pieces*—Turned cylinders. *Testing-machine*—B.

IRON D (FIRST LOT).

Test number.	Diameter of bar.	Dimensions of test-pieces. Diameter. Original.	Diameter. At tensile limit.	Diameter. At fracture.	Length. Original.	Length. At tensile limit.	Length. At fracture.	Reduced area. At tensile limit.	Reduced area. At fracture.	Per cent. of elongation— At tensile limit.	Per cent. of elongation— At fracture.	Stress per square inch in pounds. Elastic limit.	First tensile limit.	Second tensile limit.	Period of rest between strains.	Gain by rest. Per square inch of original area—pounds.	Per square inch of original area—per cent.
	″	″	″	″	″	″	″										
429	2	.797	....	.679	3.20	.....	3.80	.....	72.6	.....	18.8	32,071	48,585	....	None	......	....
430	"	.790	.729	.675	3.20	3.60	3.63	83.7	82.8	12.5	13.4	30,066	46,624	53,555	1 day	6,931	14.8
431	1⅞	.797	....	.623	3.20	.....	4.10	.....	61.1	.....	28.1	29,866	47,850	....	None	......	....
432	"	.797	.697	.640	3.18	3.98	4.03	76.5	64.5	25.1	26.7	33,474	46,624	54,019	1 day	7,395	15.8
433	1¾	.797	....	.603	3.20	.....	4.15	....	56.7	.....	29.7	30,060	48,300	....	None	......	....
434	"	.797	.693	.620	3.18	3.97	4.08	75.6	60.5	23.6	28.3	32,071	47,850	55,723	1 day	7,873	16.4
435	1⅝	.564	....	.465	2.25	.....	2.75	.....	67.6	.....	22.2	33,862	52,030	....	None	......	....
436	"	.564	.520	.494	2.27	2.67	2.75	85.1	76.8	16.7	21.1	34,823	51,435	60,041	1 day	8,606	16.7
437	1½	.564	....	.452	2.28	.....	2.83	.....	64.3	.....	25.2	33,322	49,209	....	None	......	....
438	"	.565	.510	.480	2.25	2.75	2.82	81.5	68.2	20.6	25.3	31,910	49,758	56,639	1 day	6,881	13.9
439	1⅜	.564	....	.415	2.25	.....	2.98	.....	54.2	....	32.4	36,321	51,635	....	None	......	....
440	"	.564	.490	.486	2.25	2.78	2.88	75.5	59.8	23.5	28.0	36,345	51,034	59,840	1 day	8,806	16.5
441	1¼	.564	....	.364	2.25	.....	3.00	.....	41.7	....	33.3	32,022	49,734	....	None	......	....
442	"	.564	.481	.400	2.25	2.80	2.92	72.0	50.3	24.4	30.2	30,020	50,334	57,539	1 day	7,205	14.1

One of each pair of test-pieces turned from the same bar to nearly uniform dimensions, was broken by continued application of stress. The companion piece was released from stress at tensile limit and rested one day, then broken.

Investigation—Comparison of strength, &c., of rough and turned bars. *Test-pieces*—Bars as rolled and as reduced by lathe. *Testing-machine*—A.

IRONS C AND D.

[Bars purchased for testing purposes.]

Test number.	Iron.	Diameter of bar.	Rough or turned.	Dimensions of test-pieces. Diameter. Original.	Diameter. At fracture.	Length. Original.	Length. At fracture.	At fracture. Reduced area.	At fracture. Per cent. of elongation.	Stress per square inch in pounds. At elastic limit.	At tensile limit.	Excess of strength, pounds. Rough exceeds turned.	Turned exceeds rough.
		″		″	″	″	″						
443	D	1	R	1.02	.695	4.40	5.65	46.1	28.4	36,429	52,701	....	......
444	D	"	R	1.02	.683	4.43	5.50	45.5	24.1	35,495	52,715	....	......
445	D	"	R	1.01	.728	4.03	5.30	50.8	31.5	37,330	55,377	....	......
Av.	....	......	.....	1.02	.702	4.29	5.48	47.5	28.0	36,418	53,598	....	......
446	D	1	T	.969	.667	3.90	5.03	47.4	28.9	32,544	52,769	....	......
447	D	"	T	.970	.671	3.75	4.75	47.9	26.4	33,830	51,625	....	......
448	D	"	T	.966	.667	3.65	4.78	46.3	31.2	33,888	51,848	....	......
449	D	"	T	.970	.650	3.63	4.78	45.0	31.7	34,918	53,453	....	......
Av.	....	......	.....	.969	.664	3.73	4.84	46.6	29.6	33,871	52,424	1,174	......
450	C	2	R	2.01	1.50	6.00	8.19	50.7	36.5	24,050	49,768	33	......
451	C	"	T	1.92	1.42	6.00	8.48	51.4	41.3	23,574	49,735	....	......

Tension tests upon round bars of rolled iron—Continued.

IRONS C AND D—Continued.

Test number.	Iron.	Diameter of bar.	Rough or turned.	Dimensions of test-pieces.						Stress per square inch in pounds.		Excess of strength, pounds.	
				Diameter.		Length.		At fracture.					
				Original.	At fracture.	Original.	At fracture.	Reduced area.	Per cent. of elongation.	Elastic limit.	Tensile limit.	Rough exceeds turned.	Turned exceeds rough.
		"		"		"	"						
452	C	1 29/32	R	1.90	1.60	10.00	11.47	76.0	19.7	27,067	49,095	369	......
453	C		T	1.83	1.37	8.00	10.23	56.0	28.0	27,010	48,726	....	......
454	C	1 27/32	R	1.80	1.49	11.00	12.98	68.6	18.0	33,183	49,512	....	......
455	C		T	1.75	1.45	7.50	9.48	68.7	26.0	29,934	51,367	....	1,855
456	C	1 25/32	R	1.77	1.25	10.00	12.55	50.0	25.4	27,700	51,499	....	......
457	C		T	1.70	1.23	5.00	6.66	58.4	33.2	32,990	51,895	....	396
458	D	1 23/32	R	1.72	1.47	11.00	13.00	78.1	18.1	29,748	51,233	1,814	......
459	D		T	1.64	1.43	7.00	8.13	76.0	16.1	30,222	49,419	....	......
460	D	1 21/32	R	1.64	1.29	10.00	11.67	61.9	16.7	27,268	51,127	742	......
461	D		T	1.57	1.19	5.50	7.12	57.5	30.0	32,279	50,385	....	......
462	D	1 9/16	R	1.54	1.07	6.00	7.62	48.3	27.0	32,472	52,156	....	......
463	D		T	1.50	1.03	5.00	6.56	47.1	31.2	33,681	53,347	....	1,191

Investigation—Effect of varying reduction by the rolls upon the same bar. *Test-pieces*—Bars as rolled and turned cylinders. *Testing-machines*—A and B.

IRON C and D.

[Bars purchased for testing purposes.]

Bar.			Form of test-pieces.	Dimensions of test-pieces.						Stress per square inch in pounds.		Ratio of elastic to tensile limit.
				Diameter.		Length.		At fracture.				
Test number.	Iron.	Diameter.		Original.	At fracture.	Original.	At fracture.	Reduced area.	Per cent. of elongation.	At elastic limit.	At tensile limit.	
		"		"	"	"	"					
464	C	1⅜	Round bar..	1.38	.98	6.50	8.14	50.5	25.2	33,422	58,296	57.3
465	C	1¼	Round bar..	1.24	1.22	5.75	5.83	96.8	1.4	34,188	43,040	79.4
466	C	1⅛	Round bar..	1.13	1.11	7.25	7.30	97.5	.7	37,088	50,045	74.1
467	C	1	Round bar..	1.02	.86	6.00	7.60	71.1	56.7	36,960	56,541	65.4
468	D	1⅜	Round bar..	1.38	1.00	6.50	7.13	52.5	9.7	35,026	57,486	60.9
469	D	1¼	Round bar..	1.25	1.10	5.50	6.04	77.5	9.8	33,740	53,952	62.5
470	D	1⅛	Round bar..	1.12	.94	7.00	8.19	70.5	17.0	33,495	54,000	62.0
471	D	1	Round bar..	1.02	.78	5.75	6.10	58.5	6.0	37,694	60,947	61.8
472	C	1⅜	Cylinder....	.604	.453	2.98	3.94	56.9	32.1	26,526	50,267	52.7
473	C	1	Cylinder....	.497	.339	2.49	3.38	46.5	35.4	30,799	54,608	56.4
474	D	1⅜	Cylinder....	.600	.430	3.02	3.94	51.4	36.3	26,526	49,515	53.6
475	D	1	Cylinder....	.500	.363	2.55	3.32	52.7	30.2	30,431	51,949	58.6

The above tests were upon two bars, one each of irons C and D, from which, when reduced by rolls to 1⅜″, test-pieces were cut, and the bars subsequently reduced to 1¼″ and 1″, pieces being cut off at each reduction, the object being to trace the effect upon the same bar of the action of the rolls. The results are even more irregular than the process by which the bars were produced.

Tension tests upon round bars of rolled iron—Continued.

Investigation—Comparison of strength of rough and turned bars. *Test-pieces*—Bars as rolled, as reduced by lathe. *Testing-machines*—A and B.

IRON E.

[Bars purchased for testing purposes.]

Test number.	Diameter of bar.	Rough or turned.	Dimensions of test-pieces.						Stress in pounds at—			Excess of strength, pounds.	
			Diameter.		Length.		At fracture.						
			Original.	At fracture.	Original.	At fracture.	Reduced area.	Per cent. of elongation.	Elastic limit per square inch.	Observed.	Tensile limit per square inch.	Rough exceeds turned.	Turned exceeds rough.
	″		″	″	″	″							
476	1⅛	R	1.15	.82	5.00	6.46	50.9	29.2	33,549	55,152	53,097	....	....
477	"	T	1.09	.75	6.00	7.58	47.4	26.3	28,086	....	53,497	....	400
478	1¼	R	1.26	.95	4.00	5.17	56.9	29.2	22,712	67,200	53,898	584	....
479	"	T	1.17	.85	6.00	7.61	52.8	27.0	23,306	....	53,309	....	....
480	1⅜	R	1.39	1.00	6.00	7.76	51.8	29.3	25,930	79,296	52,254	411	....
481	"	T	1.35	1.00	6.00	7.61	54.2	27.0	30,181	....	51,843	....	....
482	1½	R	1.50	1.07	4.00	5.31	50.9	32.7	32,869	97,920	55,415	....	....
483	"	T	1.44	1.01	6.00	8.09	49.2	35.0	29,591	....	55,409	....	6
484	1⅝	R	1.63	1.30	5.00	6.52	63.7	30.4	27,695	108,384	51,940	1,096	....
485	"	T	1.54	1.25	6.00	7.44	65.9	24.0	27,110	....	50,844	....	....
486	1¾	R	1.75	1.34	8.00	9.96	58.7	24.5	26,541	124,128	51,606	....	....
487	"	T	1.64	1.24	8.00	10.80	57.2	28.7	27,722	....	51,740	....	135
488	1⅞	R	1.89	1.39	9.00	11.44	54.2	27.4	27,156	142,992	50,880	1,836	....
489	"	T	1.81	1.38	10.00	12.85	58.1	23.5	25,445	126,192	49,044	....	....
490	1⅞	T	.976	.729	3.90	5.12	55.8	31.3	27,667	....	49,088	....	....
491	"	T	.976	.775	3.90	4.95	63.1	26.9	28,071	....	50,458	....	....
492	"	T	.976	.725	3.90	5.20	55.2	33.3	27,147	....	49,054	....	....
493	"	T	.976	.731	3.90	5.00	56.1	28.2	27,077	....	49,225	....	....
494	"	T	.976	.780	3.90	4.97	63.9	26.9	25,395	....	48,199	....	....
495	"	T	.976	.759	3.90	5.07	61.0	30.0	25,997	....	48,399	....	....
496	"	T	.976	.775	3.90	5.01	63.1	28.4	26,732	....	49,709	....	....
497	"	T	.976	.779	3.90	5.07	63.7	30.0	26,231	....	48,152	....	....
Av.	....	......	9.76	.755	3.90	5.08	60.3	29.4	26,789	....	49,038	1,842	....
498	2	......	2.03	.177	6.00	7.52	76.1	25.3	27,318	....	51,818	....	....

Investigation—Character of iron as adapted for chain-cables, and effect of varying reduction from pile to bar. *Test-pieces*—Bars as rolled. *Testing-machine*—A.

IRON F (FIRST LOT).

Test number.	Diameter of bar.	Dimensions of test-pieces.						Stress in pounds at—				Ratio of elastic to tensile limit.
		Diameter.		Length.		At fracture.		Elastic limit per square inch.	Tensile limit.			
		Original.	At fracture.	Original.	At fracture.	Reduced area.	Per cent. of elongation		Observed.	Per square inch original area.	Per square inch fractured area.	
	″	″	″	″	″							
499	1⅛	1.12	.80	13.5	16.50	51.1	22.2	32,640	52,800	53,800	105,053	61.8
500	"	1.12	.78	13.5	16.23	48.5	20.2	34,180	53,180	53,978	108,486	64.2
Av.	....	......	......	......	......	49.8	21.0	33,410	52,990	53,889	106,769	63.0
501	1¼	1.25	.89	15.5	18.90	50.7	22.0	32,469	65,280	53,211	104,934	61.0
502	"	1.25	.90	15.5	19.00	51.9	22.5	31,687	64,700	52,730	101,697	60.0
Av.	....	......	......	......	......	51.3	22.2	32,078	64,990	52,970	103,315	60.5

Tension tests upon round bars of rolled iron—Continued.

IRON F (FIRST LOT)—Continued.

Test number.	Diameter of bar.	Dimensions of test-pieces.						Stress in pounds at—				Ratio of elastic to tensile limit.
		Diameter.		Length.		At fracture.		Elastic limit per square inch.	Tensile limit.			
		Original.	At fracture.	Original.	At fracture.	Reduced area.	Per cent of elongation.		Observed.	Per square inch original area.	Per square inch fractured area.	
	″	″	″	″	″							
503	1⅜	1.38	1.01	16.5	19.93	58.6	20.7	82,346	76,800	51,347	95,856	63.0
504	"	1.38	1.00	16.5	18.93	52.6	14.7	81,689	77,670	51,245	99,007	61.7
Av.	....	......	......	....	....	53.2	17.7	81,992	77,235	51,296	97,431	62.3
505	1½	1.50	1.09	17.5	19.00	52.9	8.6	81,511	91,200	51,612	97,783	61.9
506	"	1.50	1.09	17.5	20.00	52.9	14.3	82,597	92,550	52,376	99,185	62.2
Av.	....	......	......	....	....	52.9	11.4	82,054	91,875	51,994	98,484	61.6
507	1⅝	1.62	1.16	19.0	22.80	51.3	17.4	83,766	106,560	51,698	100,832	65.3
508	"	1.62	1.18	19.0	22.87	53.1	20.4	84,048	108,480	52,629	99,204	64.6
Av.	....	......	......	....	....	52.2	18.9	83,907	107,520	52,163	100,018	64.9
509	1¾	1.75	1.24	18.0	22.05	58.7	22.5	82,329	120,960	50,291	85,768	64.2
510	"	1.75	1.25	18.0	21.62	51.5	20.1	82,130	122,880	51,089	100,130	62.8
Av.	....	......	......	....	....	55.1	21.3	82,229	121,920	50,690	92,949	63.5
511	1⅞	1.88	1.42	20.0	24.40	57.1	22.0	82,508	141,300	50,902	89,221	63.8
512	"	1.87	1.35	20.0	24.82	52.2	21.6	83,625	140,550	51,176	98,190	65.7
Av.	....	......	......	....	....	54.6	22.8	83,067	140,925	51,039	93,706	64.7
513	2	1.99	1.49	20.0	23.50	56.1	17.5	27,779	153,600	49,885	88,093	56.2
514	"	1.99	1.48	20.0	24.17	55.4	20.8	27,490	150,920	48,522	87,744	56.6
Av.	....	......	......	....	....	55.7	19.1	27,634	152,260	48,956	87,918	56.4

Investigation—Comparison of strength, &c., of rough and turned bars. *Test-pieces*—Bars as rolled and slightly reduced. *Testing-machines*—B.

IRON F (FIRST LOT).

Test number.	Diameter of bar.	Rough or turned.	Dimensions of test-pieces.						Stress in pounds at tensile limit.			
			Diameter.		Length.		At fracture.		Per square inch original area.	Per square inch fractured area.	Rough exceeds turned.	Turned exceeds rough.
			Original.	At fracture.	Original.	At fracture.	Reduced area.	Per cent. of elongation.				
	″		″	″	″	″						
515	1	R	1.015	.880	3.80	4.48	*76.0	17.8	52,539	....	....	....
516	"	R	1.014	.747	4.00	4.95	53.2	23.7	52,370	96,680	....	....
517	"	R	1.017	.761	4.00	4.96	57.0	24.0	53,025	94,490	....	....
Av.	......	......	......	......	......	......	55.1	21.8	52,645	95,585	....	....
518	1	T	.897	.786	3.52	4.28	*77.0	21.6	51,945	....	....	....
519	"	T	.896	.665	3.47	4.32	55.1	24.4	52,975	96,175	....	....
520	"	T	.895	.667	3.57	4.46	55.6	24.7	52,575	94,444	....	....
Av.	......	......	......	......	......	......	55.1	23.5	52,498	95,309	147	....
521	1	R	1.018	.748	3.95	4.96	54.5	25.9	51,800	95,410	....	....
522	"	R	1.017	.748	3.72	4.76	54.5	28.1	52,175	96,260	....	....
523	"	R	1.018	.753	3.90	4.83	55.0	24.8	52,660	95,905	....	....
524	"	R	1.016	.742	3.90	4.83	57.8	24.3	51,987	90,045	....	....
Av.	......	......	......	......	......	......	55.4	25.6	52,155	94,430	....	....
525	1	T	.872	.631	3.60	4.68	52.4	29.8	51,657	98,656	....	....
526	"	T	.897	.661	3.54	4.50	54.4	27.5	51,076	94,333	....	....
527	"	T	.892	.652	3.57	4.50	53.5	29.1	51,888	97,100	....	....
528	"	T	.892	.660	3.57	4.50	56.4	29.1	51,567	94,195	....	....
Av.	......	......	......	......	......	......	54.2	28.8	51,547	96,071	608	....

Tension tests upon round bars of rolled iron—Continued.

IRON F (FIRST LOT)—Continued.

Test number.	Diameter of bar.	Rough or turned.	Dimensions of test-pieces. Diameter. Original.	Dimensions of test-pieces. Diameter. At fracture.	Dimensions of test-pieces. Length. Original.	Dimensions of test-pieces. Length. At fracture.	Dimensions of test-pieces. At fracture. Reduced area.	Dimensions of test-pieces. At fracture. Per cent. of elongation.	Stress in pounds at tensile limit. Per square inch original area.	Stress in pounds at tensile limit. Per square inch fractured area.	Stress in pounds at tensile limit. Rough exceeds turned.	Stress in pounds at tensile limit. Turned exceeds rough.
	"		"	"	"	"						
529	⅝	R	.632	.469	2.46	3.06	55.0	24.0	56,022	101,820	......	......
530	"	R	.643	.483	2.48	2.97	56.4	19.3	58,900	104,390	......	......
531	"	R	.640	.475	2.48	3.05	55.1	22.9	55,950	101,580	......	......
532	"	R	.641	.475	2.48	2.95	55.0	18.9	56,864	103,555	......	......
533	"	R	.646	.475	2.50	3.33	54.0	32.8	55,210	102,145	......	......
534	"	R	.643	.494	2.47	2.98	59.0	18.6	60,594	102,639	......	......
Av.	......	......	......	......	......	......	**55.7**	**22.8**	**57,527**	**102,686**	......	......
535	⅝	T	.526	.400	2	2.40	58.0	20.5	58,670	101,430	......	......
536	"	T	.525	.383	2	2.57	52.0	28.5	56,460	106,670	......	......
537	"	T	.526	.387	2	2.46	54.0	26.0	56,775	104,710	......	......
538	"	T	.526	.407	2	2.52	59.9	16.5	59,130	99,540	......	......
539	"	T	.526	.389	2	2.51	52.3	25.5	57,295	109,780	......	......
Av.	......	......	......	......	......	......	**55.2**	**23.4**	**57,668**	**104,220**	......	**141**
540	⅝	R	.632	.470	2.55	3.19	55.5	25.1	56,585	102,300	......	......
541	"	R	.642	.470	2.47	3.21	53.4	25.5	54,825	103,009	......	......
542	"	R	.637	.478	2.50	2.85	56.4	22.8	55,140	92,896	......	......
543	"	R	.631	.457	2.50	3.15	52.5	26.0	56,610	107,919	......	......
544	"	R	.636	.467	2.50	3.20	53.9	25.6	55,630	103,110	......	......
545	"	R	.637	.464	2.47	......	54.0	25.5	55,090	102,040	......	......
Av.	......	......	......	......	......	......	**54.3**	**25.0**	**55,644**	**103,670**	......	......
546	⅝	T	.525	.386	2.10	2.73	54.0	30.0	55,195	101,220	......	......
547	"	T	.525	.381	2.05	2.73	52.7	32.5	55,085	104,600	......	......
548	"	T	.525	.375	2.05	2.60	50.8	26.8	54,733	107,333	......	......
549	"	T	.525	.385	2.06	2.70	53.8	31.0	54,735	101,800	......	......
550	"	T	.525	.377	2.05	2.73	51.6	33.1	55,080	106,855	......	......
Av.	......	......	......	......	......	......	**52.6**	**30.6**	**54,964**	**104,452**	**680**	......

Investigation—Establishment of standard for uniformity and elevation of limit of stress. *Test-pieces*—Turned cylinders. *Testing-machine*—B.

IRON F (FIRST LOT).

Test number.	Diameter of bar.	Dimensions of test-pieces. Diameter. Original.	Dimensions of test-pieces. Diameter. Tensile limit.	Dimensions of test-pieces. Diameter. Fracture.	Dimensions of test-pieces. Length. Original.	Dimensions of test-pieces. Length. Tensile limit.	Dimensions of test-pieces. Length. Fracture.	Dimensions of test-pieces. Reduced area. Tensile limit.	Dimensions of test-pieces. Reduced area. Fracture.	Dimensions of test-pieces. Per ct. elonga'n. Tensile limit.	Dimensions of test-pieces. Per ct. elonga'n. Fracture.	Stress in pounds per square inch. Elastic limit.	Stress in pounds per square inch. Tensile limit. First test.	Stress in pounds per square inch. Tensile limit. Second test.	Stress in pounds per square inch. Period between strains.	Gain in strength per square inch. Pounds.	Gain in strength per square inch. Per cent.	Ratio of elastic to tensile limit.
	"	"		"	"		"											
551	1	.872	....	.631	3.60	....	4.68	....	52.4	....	30.0	35,164	51,658	......	......	......	....	68.0
552	"	.897	....	.631	3.54	....	4.52	....	54.3	....	27.7	33,389	51,073	......	......	......	....	65.3
553	"	.892	....	.653	3.58	...	4.63	...	53.4	...	29.3	34,245	51,887	......	......	......	....	65.9
554	"	.892	....	.660	3.58	...	4.60	....	54.7	....	28.5	35,205	51,667	......	......	......	....	68.2
Av.	....	....	....	...	..	....	....	..	**52.9**	..	**28.9**	**34,501**	**51,546**	......	......	......	...	**66.8**
555	1⅛	.564	....	.413	2.25	..	2.94	....	52.6	..	0.7	36,725	53,530	......	......	......	....	68.6
556	"	.564	....	.408	2.25	..	2.95	..	52.3	..	1.1	37,625	53,036	......	......	......	...	70.2
Av.	....	....	....	...	....	...	....	..	**52.4**	...	**30.9**	**37,175**	**53,283**	......	......	......	....	**69.4**
557	1¼	.564	....	.400	2.19	...	2.90	....	53.8	....	32.4	32,022	51,034	......	......	......	....	62.7
558	"	.566	....	.401	2.26	...	2.94	...	50.2	....	30.0	33,684	51,471	......	......	......	..	65.4
559	"	.564	....	.408	2.25	....	2.95	....	52.3	....	31.1	37,625	53,036	......	......	......	....	70.0
Av.	....	....	....	...	....	...	....	....	**52.1**	....	**31.2**	**34,443**	**51,847**	......	......	......	....	**66.0**

Tension tests upon round bars of rolled iron—Continued.

IRON F (FIRST LOT)—Continued.

Test number.	Diameter of bar.	Dimensions of test-pieces. Diameter. Original.	Diameter. Tensile limit.	Diameter. Fracture.	Length. Original.	Length. Tensile limit.	Length. Fracture.	Red'c'd area. Tensile limit.	Red'c'd area. Fracture.	Per ct. elong. Tensile limit.	Per ct. elong. Fracture.	Stress in pounds per square inch. Elastic limit.	Tensile limit. First rest.	Tensile limit. Second rest.	Period between strains.	Gain in strength per square inch. Pounds.	Gain in strength per square inch. Per cent.	Ratio of elastic to tensile limit.
	″	″		″	″		″											
560	1¼	.564	.479	.415	2.27	2.84	2.95	75.6	51.7	25.1	30.0	34,075	50,840	55,037	1 day	4.697	9.2	67.1
561	1⅜	.565	....	.406	2.27	....	2.93	....	51.7	....	30.4	34,501	50,275	....	......	....	....	68.6
562	"	.567	.496	.418	2.26	2.71	2.86	76.6	53.9	19.9	26.5	35,645	49,705	55,448	1 day	5,743	11.5	71.7
Av.	....	....	....	....	....	....	....	....	....	....	....	....	....	....	......	....	....	70.0
563	1½	.565	....	.404	2.20	....	2.89	..	51.2	....	31.4	33,205	51,454	....	......	....	....	64.5
564	"	.565	.493	.415	2.27	2.81	2.99	76.1	53.9	23.8	31.7	35,890	51,154	55,941	1 day	4.787	9.3	70.2
Av.	....	....	....	....	....	....	....	....	....	....	....	....	....	....	......	....	....	67.3
565	1⅝	.566	....	.410	2.18	....	2.93	....	52.5	....	34.4	34,739	51,371	....	......	....	....	66.9
566	"	.564	.476	.413	2.23	2.78	2.92	71.2	53.6	24.6	30.9	34,023	51,235	55,950	1 day	4.715	9.2	66.6
Av.	....	....	....	....	....	....	....	....	....	....	....	....	....	....	......	....	...	66.8
567	1¾	.804	....	....	3.19	....	4.19	...	52.6	....	31.3	35,454	50,917	....	......	....	....	69.6
568	"	.790	.698	....	3.19	3.91	4.12	76.9	55.6	22.2	28.8	34,688	50,842	53,044	1 day	2.702	5.3	68.8
Av.	....	....	....	....	....	....	....	....	....	....	....	....	....	....	......	....	....	69.3
569	1⅞	.799	....	.576	3.13	....	4.10	....	52.0	....	30.9	35,899	51,070	....	......	....	....	70.1
570	"	.803	....	.586	3.13	....	4.16	....	58.8	....	32.9	35,543	51,734	....	......	....	....	68.7
Av.	....	....	....	....	....	....	....	....	....	....	....	....	....	....	......	....	....	69.4
571	2	.798	....	.564	3.14	....	4.09	....	50.0	....	30.2	31,991	49,586	....	......	....	....	64.5
572	"	.800	....	.578	3.06	....	4.07	....	52.2	....	33.0	27,852	49,786	....	......	....	....	55.9
Av.	....	....	....	....	....	....	....	....	....	....	....	....	....	....	......	....	....	60.2

Tension tests upon crude iron.

Investigation—Character of material. *Test-pieces*—Parallelogram and cylinders. *Testing-machine*—B.

IRON F.

Test number.	Dimensions of test-pieces. Diameter. Original.	Diameter. At tensile limit.	Diameter. At fracture.	Length. Original.	Length. At tensile limit.	Length. At fracture.	Reduced area. At tensile limit.	Reduced area. At fracture.	Per cent. of elongation. At tensile limit.	Per cent. of elongation. At fracture.	Stress in pounds at— Elastic limit per square inch.	Tensile limit. Per square inch original area.	Tensile limit. Per square inch tensile limit area.	Tensile limit. Per square inch fractured area.	Ratio of elastic to tensile limit.
	″	″	″	″	″	″									
1	.503 × .982	....	.442 × .876	3.50	......	4.15	......	78.4	......	18.6	29,510	50,870	....	64,888	58.0
2	.606	.543	.468	3.00	3.64	3.79	80.8	59.6	21.8	26.3	29,646	54,093	67,357	90,697	54.8
3	.597	.....	.513	2.96	......	3.53	......	73.8	......	19.3	28,581	52,840	....	70,875	54.6
4	.611	.534	.498	3.15	3.93	4.04	76.4	66.4	24.8	28.2	31,207	48,431	63,392	72,895	64.4
5	.603	.....	.592	......	......	......	......	96.4	......	......	27,399	35,364	....	36,687	77.5

Nos. 1, 2, and 3 were "crude," of which No. 1 was a parallelogram. Nos. 4 and 5 "reheated." No. 5 was cut across grain.

The results from the first lot of iron F indicated that it was remarkably uniform in its structure, and so thoroughly ductile that there was no reason to apprehend that the results of any series of tests upon it would be impaired in value, by unaccountable anomalous breaks; for these reasons it was selected as suitable material, to be used in reinvestigating the various physical phenonema which had become manifest during the testing of the preceding irons, and the value of our results in the various investigations upon other irons can be measured by those on this; also the results from the two testing-machines can be compared. In order to obtain a complete record of the iron, crude and reheated bars from which the second lot was rolled, and rolled bars from ½ inch up to 4 inches in diameter, were procured and tested.

Tension tests upon round bars of rolled iron—Continued.

Investigation—Establishment of standard of uniformity, and effect of varying reductions from pile to bar. *Test-pieces*—Bars as rolled. *Testing-machine*—A.

IRON F (SECOND LOT).

Test number.	Dimensions of test-pieces.						Stress in pounds at—					Ratio elastic to tensile limit.
	Diameter.		Reduced area at fracture.	Length.		Per cent. elongation at fracture.	Elastic limit.		Tensile limit.			
	Original.	At fracture.		Original.	At fracture.		Observed.	Per square inch.	Observed.	Per square inch original area.	Per square inch fractured area.	
	″	″		″	″							
573	.99	.72	52.9	5.00	6.14	22.8	24,500	31,826	40,000	51,963	98,280	61.2
574	.99	.71	51.5	5.00	6.32	26.4	24,800	32,216	39,500	51,312	99,747	62.7
575	.99	.72	52.9	5.00	6.24	24.8	25,000	32,475	41,000	53,260	100,787	60.9
576	.99	.71	51.5	5.00	6.08	21.6	25,000	32,475	41,800	54,299	105,582	59.8
577	.99	.70	50.0	6.00	7.22	20.3	24,900	32,346	41,000	53,260	106,548	60.7
Av.	......	.....	51.7	....	....	23.2	24,840	32,267	40,660	52,819	102,139	61.0
578	1.10	.80	53.0	7.00	8.77	25.3	30,000	31,579	50,000	52,631	99,403	60.0
579	1.10	.79	51.6	7.00	8.78	25.4	29,800	31,368	49,000	51,579	103,222	60.8
580	1.10	.84	58.3	6.75	8.40	24.4	31,200	32,831	50,100	52,720	90,400	62.2
581	1.10	.80	53.0	6.75	8.43	24.9	30,800	32,421	49,200	51,773	97,877	62.6
582	1.10	.80	53.0	7.50	9.05	20.6	30,300	31,894	50,000	52,631	99,403	60.6
Av.	......	......	53.8	....	....	24.3	32,420	32,019	49,660	52,267	98,061	61.2
583	1.23	.93	57.2	7.00	8.37	19.5	38,000	31,986	61,000	51,346	91,302	62.0
584	1.23	.91	54.8	7.00	8.09	15.5	40,000	33,670	62,500	52,609	96,150	64.0
585	1.23	.98	63.5	7.00	7.98	14.0	41,000	34,511	65,500	55,134	86,670	62.5
586	1.23	.88	51.2	5.50	7.24	31.6	39,000	32,823	61,000	31,346	100,796	63.9
587	1.24	.89	51.6	6.00	7.02	17.0	40,000	33,123	63,600	52,666	102,234	62.9
Av.	......	......	55.7	....	....	19.5	39,000	33,222	62,520	52,620	95,431	61.0
588	1.38	1.02	54.7	8.00	9.69	21.0	53,000	35,427	78,600	52,550	92,205	67.4
589	1.38	1.06	59.0	8.00	9.33	16.8	55,000	36,764	81,500	52,489	92,403	67.4
590	1.38	1.05	57.9	8.25	10.25	24.2	50,500	33,763	76,800	51,347	88,694	65.7
591	1.38	1.02	54.7	7.00	8.53	21.8	48,000	32,092	79,700	53,286	97,540	60.2
592	1.38	1.06	59.0	7.00	8.46	20.9	51,300	34,298	76,300	51,018	86,458	67.2
Av.	......	......	57.1	....	....	20.9	51,560	34,469	78,580	52,537	91,460	65.6
593	1.50	1.10	53.8	9.00	10.98	22.0	63,600	35,993	90,000	50,993	94,736	70.6
594	1.50	1.10	58.8	9.00	11.42	27.0	63,500	35,936	91,000	51,499	95,789	69.6
595	1.50	1.14	57.8	7.50	9.35	24.6	58,500	33,105	89,800	50,820	87,978	65.1
596	1.50	1.11	55.4	9.00	12.21	35.6	58,900	33,331	92,900	52,572	96,000	63.3
Av.	......	......	55.2	....	....	24.8	61,125	34,591	90,925	51,456	93,626	67.1
597	1.625	1.22	56.0	6.00	7.36	22.6	73,000	34,978	107,000	51,590	91,531	68.2
598	1.625	1.20	54.2	6.00	7.64	27.3	72,000	34,499	106,000	51,109	93,722	67.9
599	1.625	1.20	54.2	9.75	12.08	23.9	68,100	32,635	105,300	50,782	93,112	64.6
600	1.625	1.17	51.6	9.00	11.20	24.4	68,400	32,779	105,400	50,830	98,037	64.9
601	1.625	1.22	56.7	10.00	12.59	25.9	68,500	33,236	103,500	50,538	88,544	66.2
Av.	......	......	54.5	....	....	24.8	70,000	33,625	105,440	50,970	92,989	66.3
602	1.73	1.29	55.6	8.00	9.92	24.0	70,500	29,987	116,500	49,553	88,931	60.5
603	1.73	1.28	54.9	8.00	10.02	25.2	69,500	29,561	116,500	49,553	90,387	59.6
604	1.74	1.30	55.8	7.00	8.80	25.7	71,000	29,859	118,500	49,831	89,097	59.9
605	1.74	1.26	52.5	7.20	9.10	26.4	69,100	24,852	117,200	49,287	93,933	67.4
606	1.74	1.31	56.7	10.00	13.05	30.5	72,000	30,278	120,000	50,464	89,038	60.0
Av.	......	......	55.1	....	....	26.4	70,420	28,907	117,740	49,738	90,277	61.5
607	1.86	1.35	52.7	11.00	13.30	20.9	63,600	23,408	133,000	48,943	92,942	47.8
108	1.86	1.34	51.9	11.00	13.60	23.6	63,000	23,187	131,500	48,398	93,262	47.9
609	1.86	1.37	53.9	10.00	12.63	26.3	91,600	33,711	133,100	48,948	90,224	68.8
610	1.87	1.55	68.7	9.00	10.90	21.4	93,000	33,861	136,000	49,517	72,076	68.3
611	1.86	1.38	55.1	9.00	11.12	23.5	85,700	31,593	134,590	49,499	89,924	63.7
Av.	......	......	56.4	....	....	23.1	79,380	29,132	133,620	49,061	87,680	59.3
612	2.00	1.47	54.1	12.00	14.76	23.0	84,900	27,021	149,500	47,581	88,097	56.8
613	2.00	1.45	52.6	12.00	14.83	23.5	86,000	27,371	151,000	48,058	99,515	57.0
614	2.00	1.44	51.8	12.00	14.82	23.5	85,800	27,307	150,500	47,099	92,444	57.0
615	2.00	1.47	51.1	10.00	12.45	24.5	96,900	30,844	149,000	47,428	87,791	65.0
616	2.00	1.47	54.1	10.00	12.25	22.5	98,700	31,417	149,800	47,682	88,278	65.9
Av.	......	......	53.3	....	....	23.4	90,470	28,792	149,960	47,569	91,224	60.3

Area of piles from which this set of bars was rolled: 1″, 6″ × 4″, 1⅛″ to 1½″, inclusive, 6″ × 6″, 1⅝″ to 2″, inclusive, 6″ × 10″

Tension tests upon round bars of rolled iron—Continued.

Investigation—Comparison of strength of rough and turned bars. *Test-pieces*—Bars as rolled and slightly reduced by lathe. *Testing-machine*—A.

IRON F (SECOND LOT, AND TWO BARS OF F, THIRD LOT).

[Results from rough bars are the averages given in preceding table.]

Test number.	Bars.		Dimensions of test-pieces.						Stress in pounds at—			Ratio of elastic to tensile limit.	Pounds.	
			Diameter.		Length.		At fracture.		Elastic limit per square inch.	Tensile limit.				
	Diameter.	Rough or turned.	Original.	At fracture.	Original.	At fracture.	Reduced area.	Per cent. of elongation.		Per square inch original area.	Per square inch fractured area.		Rough exceeds turned.	Turned exceeds rough.
	″		″	″	″	″								
573 to 577	1	R	.99	.72	5.00	6.19	54.7	23.2	32,267	52,819	102,139	61.0	9	......
617	"	T	.95	.68	5.00	6.40	51.2	28.0	32,798	52,810	102,422	62.0	......	......
578 to 582	1⅛	R	1.10	.81	7.00	8.89	53.8	24.3	32,019	52,267	98,061	61.2	598	......
618	"	T	.99	.72	6.75	8.85	54.2	23.7	33,762	51,675	98,477	65.3	......	......
583 to 587	1¼	R	1.23	.92	6.40	7.74	55.7	19.5	33,222	52,620	95,431	62.9	671	......
619	"	T	1.13	.83	5.50	6.72	54.3	22.2	33,300	51,949	96,285	63.9	......	......
588 to 592	1⅜	R	1.33	1.04	7.65	9.19	57.1	20.9	34,469	52,537	91,460	65.6	2,134	......
620	"	T	1.30	.95	7.00	8.48	53.4	21.1	30,212	50,403	94,385	59.9	......	......
593 to 596	1½	R	1.50	1.11	8.60	11.00	55.2	24.8	34,591	51,456	93,626	67.1	797	......
621	"	T	1.40	1.00	7.50	9.40	51.1	25.3	32,675	50,709	99,567	64.3	......	......
597 to 601	1⅝	R	1.62	1.20	8.16	10.17	54.5	24.8	33,625	50,970	92,989	66.3	1,365	......
622	"	T	1.55	1.11	9.00	11.15	......	23.9	31,400	49,605	96,724	54.9	......	......
602 to 606	1¾	R	1.74	1.25	8.00	10.18	55.1	26.4	28,907	49,788	90,277	61.5	......	......
623	"	T	1.61	1.17	7.20	9.11	52.7	26.5	34,482	50,201	95,060	68.6	......	463
607 to 611	1⅞	R	1.86	1.40	10.00	12.31	56.4	23.4	29,132	49,061	87,686	59.3	......	......
624	"	T	1.71	1.25	8.60	10.66	58.4	24.0	33,972	49,682	92,976	68.3	......	621
612 to 616	2	R	2.00	1.46	11.20	13.60	53.3	23.4	28,792	47,569	91,224	60.3	......	......
625	"	T	1.87	1.38	8.65	10.70	54.4	23.9	31,166	48,170	89,749	64.7	......	601
697* 698*	2¼	R	2.24	1.63	37.50	45.00	53.3	20.2	31,237	48,505	91,042	64.3	......	......
699 700	"	T	2.09	1.47	11.50	14.60	49.5	26.8	31,966	49,164	99,265	65.0	......	659
701* 702*	2½	R	2.50	1.82	37.50	43.70	52.7	20.5	29,758	47,344	89,820	63.7	......	......
703* 704*	"	T	2.36	1.68	14.00	16.80	50.6	17.0	28,932	48,478	95,707	59.6	......	1,134

* Third lot of iron F. The two lots being of same material, the tests are fairly comparable with the results from smaller bars of second lot, and are reproduced here for ready comparison.

Tension tests upon round bars of rolled iron—Continued.

Investigation—Establishment of a standard of uniformity, by which the results of a series of elevations of limit of stress, comparison of rough and turned bars, variation in strength due to variation in diameter, &c., tests could be measured. *Test-pieces*—Turned cylinders. *Testing-machine*—B.

IRON F (SECOND LOT).

End from which cut.	Test number.	Diameter of bars.	Dimensions of test-pieces.										Stress in pounds per square inch at—				Ratio of elastic to tensile limit.
			Diameter.			Length.			Reduced area.		Per cent. of elongation.		Elastic limit.	Tensile limit.			
			Original.	At tensile limit.	At fracture.	Original.	At tensile limit.	At fracture.	At tensile limit.	At fracture.	At tensile limit.	At fracture.		Per original area.	Per tensile limit area.	Per fracture area.	
			"	"	"	"	"	"									
W	626	1	.502	.439	.356	2.50	3.00	3.23	76.5	50.3	22.0	25.2	41,940	51,823	67,040	101,971	......
W	627	"	.504	.440	....	2.58	3.16	....	76.2	....	22.2	....	37,844	50,877	67,776	....	......
C	628	"	.503	.430	.357	2.35	2.82	3.06	73.1	50.4	20.0	30.1	36,739	51,205	70,075	101,658	......
C	629	"	.503	.424	.364	2.25	2.76	2.95	71.1	52.4	23.0	30.8	37,493	51,708	72,769	98,741	......
C	630	"	.503	.425	....	2.32	2.81	....	70.9	....	20.9	....	33,866	51,675	72,938	....	......
	Av..	....	.503	.431	.359	2.40	2.91	3.08	73.5	51.0	23.6	28.7	37,576	51,457	69,919	100,790	73.1
W	631	1⅛	.500	.457	....	2.55	2.95	....	83.5	....	15.7	....	32,742	50,165	60,060	....	......
W	632	"	.500	.425	.362	2.50	3.02	3.21	72.0	53.0	21.0	28.0	33,728	50,728	70,472	97,163	......
	Av..	....	.500	.441	.362	2.53	2.98	3.21	77.8	53.0	18.3	28.0	33,235	50,446	65,266	97,163	65.9
W	633	1¼	.552	.477	.395	2.72	3.27	3.50	74.7	55.4	20.3	28.6	36,982	49,726	66,592	97,111	......
C	634	"	.554	.477	.405	2.77	3.42	3.58	74.2	53.5	23.4	29.6	32,054	50,197	67,711	93,929	......
	Av..	....	.553	.477	.400	2.75	3.34	3.54	74.5	54.4	21.8	29.1	34,518	49,961	67,151	95,520	69.1
W	635	1⅜	.601	.524	.427	2.97	3.71	3.91	76.1	50.6	24.9	31.6	37,102	49,087	64,587	97,241	......
C	636	"	.601	.523	.434	2.99	3.48	3.58	75.7	52.1	16.4	20.0	38,646	49,351	65,176	94,639	......
	Av..	....	.601	.523½	.430	2.98	3.59	3.74	75.9	51.3	20.6	25.8	37,874	49,219	64,881	95,940	76.9
W	637	1½	.654	.578	.464	3.25	4.00	4.26	78.6	50.3	23.2	31.1	28,575	49,118	62,881	97,581	......
W	638	"	.653	.575	.469	3.21	3.79	4.17	77.5	51.6	18.0	29.8	38,818	49,641	64,016	96,239	......
C	639	"	.653	.573	.474	3.20	3.98	4.15	77.5	55.4	22.8	29.6	38,444	49,865	64,753	94,639	......
	Av..	....	.653	.575	.469	3.22	3.97	4.19	77.7	52.4	21.6	30.2	35,279	49,541	63,883	96,153	71.3

W	640	1¼	.725	.626	.524	3.63	4.42	4.65	74.6	52.3	21.8	28.1	34,034	49,530	66,439	94,829	......
W	641	"	.728	.629	.518	3.62	4.55	4.75	74.7	50.7	25.7	31.2	38,437	49,250	65,980	97,276	......
C	642	"	.726	.636	.554	3.55	4.38	....	76.8	58.8	18.9	....	31,718	49,676	64,730	85,814	......
	Av..	....	.726	.630	.532	3.60	4.44	4.70	75.4	53.8	22.1	29.6	35,030	49,488	65,716	93,139	70.8
W	643	1½	.800	.712	.578	4.00	4.93	5.21	79.2	51.8	23.3	30.2	37,096	49,487	62,405	96,870	......
W	644	"	.801	.710	.596	3.97	4.89	5.15	78.6	55.4	23.2	29.7	39,687	49,314	62,768	89,074	......
C	645	"	.805	.704	.571	4.04	5.07	5.27	76.7	50.3	24.2	30.4	35,790	49,710	64,988	98,801	......
C	646	"	.800	.710	.569	4.10	4.96	5.35	78.8	50.6	20.9	30.5	33,819	49,736	64,147	98,301	......
	Av..	...	.801	.709	.580	4.52	4.95	5.24	78.3	51.9	22.9	30.2	36,823	49,549	63,577	95,637	74.3
W	647	1¾	.875	.778	.634	4.30	5.30	5.58	79.0	52.0	23.8	29.5	....	48,559	61,422	92,550	......
W	648	"	.875	.776	.632	4.30	5.14	5.58	78.6	52.2	19.5	29.5	26,110	48,560	61,740	93,082	......
C	649	"	.875	.770	.626	3.85	....	5.10	77.4	51.2	....	32.5	25,304	49,225	63,340	96,172	......
C	650	"	.874	.774	.625	4.37	5.35	5.65	78.4	51.1	22.4	29.4	30,505	48,922	62,380	95,667	......
	Av..	....	.875	.774	.629	4.20	5.26	5.48	78.3	51.6	21.7	30.3	27,326	48,817	62,720	94,368	......
W	651	2	1.010	.897	.750	5.00	6.17	6.45	78.7	55.5	23.4	23.0	32,676	48,308	61,481	87,261	......
W	652	"	1.190	1.050	.872	5.88	7.30	7.69	77.8	53.7	24.1	30.8	....	48,473	62,011	90,422	......
C	653	"	1.000	.883	.742	4.93	6.14	6.45	78.0	55.0	24.5	31.0	35,790	46,982	60,254	85,336	......
C	654	"	1.000	.803	.718	4.89	5.97	6.42	79.8	51.7	22.1	31.2	29,284	47,301	59,316	91,753	......
	Av..	...	1.050	931	.770	5.17	6.39	6.75	78.8	54.0	23.5	30.5	32,583	47,766	60,765	88,693	68.3

The bars from which the above cylinders were turned were those whose tests as entire bars, and as slightly reduced by lathe, are given Nos. 573 to 625, inclusive. Their results furnish valuable data by which the results obtained by the two machines and methods can be compared, as in the table (page 67).

During the manufacture of these bars they were, after passing through the rolls, of lengths from 30 to 50 feet, and for convenience the outer ends were thrust into the open air under a sliding door; the temperature of the air outside was 28°, at the inner ends of bars about 60°. It was thought possible that this difference in rapidity of cooling might produce some difference in the two ends of the bars, hence pieces for test were cut from each end of each bar, and marked W or C, as they came from the warm or cold end. Such differences as existed in their characteristics are given in the table on page 71.

Tension tests upon round bars of rolled iron—Continued.

Investigation—Elevation of limit of stress. Comparative effect upon form and strength of continued and intermittent strains. *Test-pieces*—Turned cylinders. *Testing-machine*—B.

IRON F (SECOND LOT)—Continued.

[The results marked † are those previously given upon pieces broken by continued strain, and are reproduced for ready comparison.]

Warm or cold end of bar.	Test number.	Diameter of bars.	Dimensions of test-pieces.										Stress in pounds per square inch.					
			Diameter.			Length.			Reduced area in per cent. of original area.		Per cent. of elongation.		Ultimate stress at—				Gain by rest.	
			Original.	At tensile limit.	At fracture.	Original.	At tensile limit.	At fracture.	At tensile limit.	At fracture.	At tensile limit.	At fracture.	Elastic limit.	First tensile limit.	Period of rest.	Second tensile limit.	Pounds per square inch.	Per cent.
		"	"	"	"	"	"	"										
W	655	1	.502	.436	.367	2.42	2.97	3.18	76.2	....	22.2	29.3	44,214	51,536	8 days	60,631	9,095	17.6
	†626 to 630	......	....	....	....	....	....	....	73.5	51.0	23.6	28.7	....	51,457	....	....	....	......
W	656	1⅛	.501	.427	.381	2.50	3.07	3.19	72.7	53.8	22.8	27.6	32,465	50,474	18 days	59,864	9,390	18.6
C	657	"	.500	.433	.374	2.46	3.01	3.10	75.0	55.9	24.5	26.0	32,340	50,178	180 days	59,231	9,053	18.1
C	658	"	.500	.400	.373	2.40	2.95	3.10	70.6	55.7	25.4	29.1	32,300	50,178	18 days.	58,314	8,136	16.1
C	659	"	.500	.400	.372	2.41	3.02	3.09	74.7	55.4	25.0	28.2	31,991	50,165	18 days	54,749	4,584	9.0
	Av......	......	....	....	....	....	....	....	73.2	55.2	24.4	27.7	....	50,244	....	....	....	......
	†631, 632	......	....	....	....	....	....	....	77.8	53.0	18.3	28.0	....	50,446	....	....	....	......
W	660	1¼	.552	.447	.415	2.73	3.41	3.58	74.7	56.5	24.9	31.1	37,401	49,935	3 days	58,251	8,316	17.0
W	661	"	.550	.478	.395	2.73	3.32	3.54	75.6	51.6	21.6	29.6	36,826	49,877	3 minutes...	50,614	737	1.5
C	662	"	.553	.488	.411	2.72	3.45	3.58	77.9	55.3	26.8	31.3	31,224	49,962	8 days	56,207	6,245	12.5
C	663	"	.550	.476	.392	2.68	3.16	3.37	74.9	50.9	18.0	25.5	32,302	50,825	1 minute....	51,351	526	1.0
	Av	......	....	....	....	....	....	....	75.8	53.6	22.8	29.4	....	50,149	....	....	....	......
	†633, 634	......	....	....	....	....	....	....	74.5	54.4	21.8	29.1	....	49,961	....	....	....	......
W	664	1⅜	.601	.523	.453	2.93	3.64	3.83	75.7	56.8	24.2	32.4	41,067	49,175	8 days	57,635	8,460	17.2
W	665	"	.603	.532	.434	3.00	3.65	3.96	77.9	51.8	21.6	32.1	....	49,024	1 minute....	49,637	613	1.3
C	666	"	.602	.526	.448	2.99	3.72	3.95	76.4	55.4	24.4	32.1	33,386	48,853	6 days	57,443	8,590	17.6
	Av.......	......	....	....	....	....	....	....	76.7	54.7	23.4	32.2	....	49,017	....	....	....	......
	†635, 636	......	....	....	....	....	....	....	75.9	51.3	20.6	25.8	....	49,219	....	....	....	......

W	667	1½	.654	.569	.479	3.26	4.01	4.16	75.7	58.7	20.7	27.6	37,806	49,207	3 days	58,049	8,782	17.8
C	668	"	.653	.566	.470	3.22	3.94	4.14	75.2	51.6	22.8	28.4	32,823	49,865	3 minutes...	50,388	523	1.0
C	669	"	.653	.575	.486	3.25	4.01	4.25	77.5	56.8	23.4	28.2	29,859	50,015	3 days	59,047	9,082	18.0
	Av........	......	....	....	....	....	....	....	76.1	54.0	22.1	28.1	....	49,712	....	....	....	......
	†637 to 639	......	....	....	....	....	....	....	77.7	52.4	21.6	30.2	....	49,541	....	....	....	......
W	670	1⅝	.725	.634	.545	3.62	4.48	4.69	76.5	56.5	23.7	29.0	36,350	50,143	3 days	58,136	7,993	15.9
C	671	"	.726	.634	.550	3.60	4.87	4.57	76.3	57.7	21.2	26.9	32,466	49,676	25 days	59,184	9,508	19.1
C	672	"	.727	.640	.557	3.50	4.43	4.50	77.5	58.7	26.5	28.5	31,558	49,867	42 days	55,949	6,082	12.2
	Av....	......	....	....	....	....	....	....	76.8	57.6	23.8	28.1	....	49,895	....	....	....	......
	†640 to 642	....	....	....	....	....	....	....	75.4	53.8	22.1	29.6	....	49,488	....	....	....	......
W	673	1¾	.803	.705	.594	4.01	4.95	5.22	77.2	54.7	23.4	30.2	37,497	49,266	3 days	57,263	7,997	16.2
C	674	"	.800	.703	.594	4.05	5.01	5.26	77.2	55.2	23.7	29.9	34,615	49,438	3 days	57,991	8,558	17.3
	Av........	......	....	....	....	....	....	....	77.2	55.0	23.5	30.1	....	49,352	....	....	....	......
	†643 to 646	......	....	....	....	....	....	....	78.3	51.9	22.9	30.2	....	49,549	....	....	....	......
W	675	1⅞	.876	.773	.654	4.36	5.36	5.59	77.9	55.8	22.9	28.2	39,741	48,531	3 days	54,655	6,124	12.6
C	676	"	.875	.768	.645	4.31	5.32	5.58	75.4	54.4	23.4	29.4	36,587	48,809	1 minute....	49,110	801	0.6
	Av........	......	....	....	....	....	....	....	76.6	55.1	23.1	28.8	....	48,670	....	....	....	......
	†647 to 650	......	....	....	....	....	....	....	78.3	51.6	21.7	30.3	....	48,817	....	....	....	......
W	677	2	.802	.699	.622	4.01	4.95	5.11	75.6	60.0	23.4	27.5	29,693	48,597	3 days	57,081	8,484	17.4
C	678	"	1.004	.888	.742	4.96	6.15	6.50	78.1	54.7	23.9	31.2	34,408	46,862	3 days	55,577	8,715	18.6
	Av........	......	....	....	....	....	....	....	76.8	57.3	23.6	29.3	....	47,729	....	....	....	......
	†651 to 654	......	....	....	....	....	....	....	78.8	54.0	23.5	30.5	....	47,766	....	....	....	......

Condensed comparison of strength, &c., of the "warm" and "cold" ends of preceding bars.

Size.	End.	Number of tests.	Reduced area.	Per cent. of elongation.	Elastic limit.	Tensile strength.	Size.	End.	Number of tests.	Reduced area.	Per cent. of elongation.	Elastic limit.	Tensile strength.	Size.	End.	Number of tests.	Reduced area.	Per cent. of elongation.	Elastic limit.	Tensile strength.
"					*Pounds.*	*Pounds.*	"					*Pounds.*	*Pounds.*	"					*Pounds.*	*Pounds.*
1	W	3	76.0	22.3	41,333	51,232	1⅜	W	3	76.6	23.5	35,951	49,095	1¾	W	3	78.3	23.2	35,060	49,339
"	C	3	71.7	21.3	36,033	51,529	"	C	2	70.1	20.4	38,559	49,126	"	C	3	77.6	22.9	34,741	49,628
1⅛	W	3	76.1	19.8	32,978	50,456	1½	W	3	77.9	20.6	35,066	49,842	1⅞	W	3	78.4	23.1	32,926	48,550
"	C	4	73.4	25.0	32,224	50,178	"	C	3	73.4	22.9	33,542	49,915	"	C	3	76.9	22.9	30,819	48,958
1¼	W	3	75.0	22.2	37,069	49,846	1⅝	W	3	75.8	23.7	36,574	49,644	2	W	3	76.3	23.6	31,184	48,459
"	C	3	75.7	22.7	31,860	50,328	"	C	3	76.9	22.2	31,914	49,740	"	C	3	78.6	23.0	33,161	47,048

Tension tests upon round bars of rolled iron—Continued.

Investigation—Establishment of standard of uniformity by which to measure results of tests in various investigations. *Test-pieces*—Bars as rolled. *Testing-machine*—A.

IRON F (THIRD LOT).

Test number.	Diameter of bar.	Dimensions of test-pieces.						Stress in pounds at—					Ratio elastic to tensile limit.
		Diameter.		Reduced area at fracture.	Length.		Per cent. elongation at fracture.	Elastic limit.		Tensile limit.			
		Original.	At fracture.		Original.	At fracture.		Observed.	Per square inch.	Observed.	Per square inch original area.	Per square inch fractured area.	
	″	″	″		″	″							
679	....	1.01	.70	48.2	5.00	6.46	29.2	30,600	38,192	41,200	51,422	107,069	74.8
680	....	1.01	.74	53.7	5.00	6.35	27.0	32,000	39,940	42,000	52,420	97,441	76.2
Av.	....	......	......	**50.9**	......	......	**28.1**	**31,300**	**39,066**	**41,600**	**51,921**	....	**75.2**
681	1⅛	1.13	.78	47.6	8.00	9.96	24.5	35,600	35,493	50,000	49,850	104,646	71.2
682		1.13	.78	47.6	8.00	9.90	23.7	35,600	35,493	50,600	50,448	106,571	70.3
Av.	....	......	......	**47.6**	......	......	**24.1**	**35,600**	**35,493**	**50,300**	**50,149**	....	**70.7**
683	1¼	1.25	.87	48.4	9.00	10.76	19.6	48,600	39,608	64,400	52,485	108,326	75.5
684	....	1.25	.94	56.5	9.00	10.95	21.7	48,600	39,608	65,000	52,974	93,660	74.8
Av.	....	......	......	**52.4**	......	......	**20.6**	**48,600**	**39,608**	**64,700**	**52,729**	....	**75.1**
685	1⅜	1.38	.97	49.4	10.00	12.08	20.8	58,400	39,037	78,400	52,406	106,089	74.5
686	....	1.38	.87	50.4	10.00	11.95	19.5	58,600	39,170	78,200	52,272	103,672	74.9
Av.	....	......	......	**49.9**	......	......	**20.1**	**58,500**	**39,103**	**78,300**	**52,339**	....	**74.7**
687	1½	1.50	1.08	51.8	13.00	16.10	23.9	61,000	34,522	89,000	50,367	97,150	68.5
688	....	1.50	1.05	49.0	13.00	16.25	25.0	63,000	35,653	90,600	51,273	104,631	69.5
Av.	....	......	......	**50.4**	......	......	**24.4**	**62,000**	**35,087**	**89,800**	**50,820**	....	**69.0**
689	1⅝	1.62	1.14	49.6	13.00	16.00	23.0	72,000	34,934	102,400	49,684	100,293	70.3
690	....	1.61	1.20	55.5	13.00	16.31	25.5	72,000	35,854	104,600	51,375	92,484	68.8
Av.	....	......	......	**52.5**	......	......	**24.2**	**72,000**	**35,394**	**103,500**	**50,529**	....	**69.3**
591	1¾	1.74	1.22	49.1	13.00	16.50	27.0	85,600	35,996	120,000	50,464	102,651	71.5
692	....	1.74	1.26	52.5	13.00	16.31	25.5	85,400	35,912	120,400	50,630	96,551	70.9
Av.	....	......	......	**50 8**	......	......	**26.2**	**85,500**	**35,954**	**120,200**	**50,547**	....	**71.2**
693	1⅞	1.87	1.35	52.2	13.00	15.50	19.1	100,000	36,416	135,600	49,380	94,758	73.7
694	....	1.87	1.32	49.8	13.00	16.31	25.5	95,600	34,818	137,600	50,109	100,584	69.7
Av.	....	......	......	**51.0**	......	......	**22.3**	**97,800**	**35,615**	**136,600**	**49,744**	....	**71.7**
695	2	2.01	1.45	52.0	13.00	16.00	......	112,000	35,297	151,600	47,777	91,823	73.8
696	....	2.01	1.44	51.3	13.00	16.25	......	115,600	36,432	152,200	47,967	93,431	75.6
Av.	....	......	......	**51.6**	......	......	**24.0**	**113,800**	**35,864**	**151,900**	**47,872**	....	**74.8**
697	2¼	2.24	1.63	53.0	37.50	45.00	20.0	122,400	31,059	189,600	48,112	90,861	64.5
698	....	2.24	1.64	53.7	37.50	45.15	20.4	123,800	31,415	192 700	48,898	91,223	64,2
Av.	....	......	......	**53.3**	......	......	**20.2**	**123,100**	**31,237**	**191,150**	**48,505**	....	**64.3**
699	2¼T	2.09	1.45	48.1	11.00	13.94	26.7	109,800	32,002	168,000	48,965	101,756	65.4
700	....	2.10	1.50	51.0	12.00	15.24	27.0	110,600	31,931	171,000	49,364	96,774	64.7
Av.	....	......	......	**49.5**	......	......	**26.8**	**110,200**	**31,966**	**169,500**	**49,164**	....	**65.0**
701	2½R	2.50	1.82	53.0	37.50	42.20	20.5	149,500	30,456	233,200	47,507	89,630	64.1
702	....	2.50	1.81	52.4	37.50	45.25	20.6	146,800	29,060	231,600	47,181	90,011	63.3
Av.	....	......	......	**52.7**	......	......	**20.5**	**148,150**	**29,758**	**232,400**	**47,344**	....	**63.7**
703	2½T	2.34	1.65	49.7	14.00	16.50	17.9	123,200	28,644	208,200	48,407	97,380	59.1
704	....	2.38	1.71	51.6	14.00	16.25	16.0	130,000	29,220	216,000	48,550	94,035	60.2
Av.	....	......	......	**50.6**	......	......	**17.0**	**126,600**	**28,932**	**212,100**	**48,478**	....	**59.6**

The strength of bars of 2¾″ up to 4″ could not be obtained by the testing-machine A. The results obtained by tests of cylinders of 1″ diameter, tested by machine B, reduced to area of bars, gives entire strength as follows:

″	Lbs.	″	Lbs.
2¾	275,889	3½	452,191
3	337,603	3¾	515,423
3¼	390,019	4	582,100

Tests Nos. 699, 700, 703, and 704 were made upon bars reduced in the lathe.

Tension tests upon round bars of rolled iron—Continued.

Investigation—Effect of varying reduction from pile to bar; also, elevation of limit of stress, produced by rest from strain for *six months*. *Test-pieces*—Turned cylinders. *Testing-machine*—B.

IRON F (THIRD LOT)—Continued.

Test numbers.	Diameter of bar.	Dimensions of test-pieces.										Stress in pounds at—							Gain by rest.		Ratio of elastic to tensile limit.
		Diameter.			Reduced area in per cent. of original.		Length.			Elongation, per cent.		Elastic limit per square inch.	First tensile limit.				Second tensile limit.				
		Original.	At tensile limit.	At fracture.	At tensile limit.	At fracture.	Original.	At tensile limit.	At fracture.	At tensile limit.	At fracture.		Observed.	Per square inch original area.	Per square inch area tensile limit.	Area fracture.	Observed.	Per square inch.	Pounds per square inch.	Per cent.	
	"	"	"	"			"	"	"												
705	1	.504	.441	.386	76.6	58.6	2.57	3.13	3.24	22.5	26.0	38,596	10,200	51,128	66,791	103,743	12,150	60,902	9,774	19.1	75.6
706	1⅛	.502	.437	.377	75.8	55.7	2.43	2.98	3.12	22.8	28.3	37,771	10,000	50,530	66,666	105,706	11,800	59,626	9,096	18.0	75.4
707	1¼	.552	.483	.408	76.6	54.6	2.67	3.28	3.46	22.8	29.0	40,534	11,750	49,101	64,137	105,935	13,850	57,877	8,776	17.8	82.7
708	1⅜	.601	.521	.445	75.2	54.0	2.96	3.49	3.66	17.8	23.6		15,850	48,819	64,962	103,839	16,150	56,885	8,066	16.6	
709	1½	.650	.577	.481	78.8	54.7	3.18	3.94	4.22	23.9	32.0	36,467	17,200	51,838	65,774	104,424	18,975	57,188	5,350	10.3	71.4
710	1⅝	.727	.640	.547	77.5	56.6	3.64	4.48	4.71	23.7	29.4	34,208	20,400	49,144	63,413	102,749	24,150	58,188	9,044	18.3	70.0
711	1¾	.802	.705	.594	77.3	54.8	3.97	4.92	5.18	23.9	29.2	38,992	24,650	48,792	63,908	104,651	29,000	57,403	8,611	17.2	80.0
712	1⅞	.877	.773	.664	77.7	58.8	4.19	5.20	5.51	24.1	31.5	37,042	29,815	49,370	63,532	102,738	35,575	58,889	9,519	19.4	75.1
713	2	1.005	.878		76.3		4.99	6.26				31,892	38,500	48,280	63,583						66.5
714	2¼	1.000	.892	.731	79.6	53.4	4.99	6.01	6.38			32,854	38,850	49,465	62,169	92,565					
715	"	1.005	.880	.731	76.7	52.9	4.82	5.95	6.23			31,679	39,000	49,155	64,123	92,923					
716	"	.997	.884	.739	75.6	54.6	4.84	6.01	6.43	24.2	32.0	31,958	38,450	49,250	62,642		45,500	58,020	8,770	17.7	65.2
Av.												32,163	38,767	49,290	62,978	92,744					
717	2½	.986	.869	.722	77.7	53.6	4.88	5.98	6.26	22.5	28.0	28,810	36,550	47,865	61,625	89,277					
718	"	1.002	.876	.730	76.4	53.1	4.84	6.00	6.27	23.8	29.6	30,406	37,500	47,558	62,208	89,605					
719	"	.995	.870	.739	76.5	56.2	4.84	6.04	6.37	24.9	30.0	30,607	37,225	47,871	62,447		44,000	58,976	11,105	22.6	62.9
Av.												29,941	37,092	47,765	62,092	89,441					
720	2¾	1.000	.877	.788	77.0	54.5	4.87	6.00	6.27	23.2	28.8	26,228	36,500	46,473	60,420	85,820					
721	"	1.002	.892	.730	79.3	53.1	4.86	6.00	6.31	23.4	29.9	27,584	36,400	46,164	58,249	86,977					
722	"	1.003	.884	.758	77.7	57.4	4.90	6.06	6.31	23.5	30.0	25,186	36,900	46,702	60,117		42,780	54,458	7,756	16.6	56.7
Av.												26,332	36,600	46,446	59,593	86,149					

Tension tests upon round bars of rolled iron—Continued.

IRON F (THIRD LOT)—Continued.

Test numbers.	Diameter of bar.	Dimensions of test-pieces.										Stress in pounds at—							Gain by rest.		Ratio of elastic to tensile limit.
		Diameter.			Reduced area in per cent. of original.		Length.			Elongation, per cent.		Elastic limit per square inch.	First tensile limit.				Second tensile limit.				
		Original.	At tensile limit.	At fracture.	At tensile limit.	At fracture.	Original.	At tensile limit.	At fracture.	At tensile limit.	At fracture.		Observed.	Per square inch original area.	Per square inch area tensile limit.	Area fracture.	Observed.	Per square inch.	Pounds per square inch.	Per cent.	
	″	″	″	″			″	″	″												
723	3	.979	.853	.707	76.0	52.2	4.78	5.99	6.30	25.8	31.8	27,656	36,100	47,954	63,167	91,951					
724	"	.982	.859	.707	76.5	51.9	4.67	5.85	6.16	25.8	31.9	27,297	36,100	47,663	62,295	91,950					
725	"	1.001	.899	.735	80.7	54.0	4.90	5.95	6.48	21.2	35.0	24,208	37,500	47,655	59,078		45,000	57,250	9,595	20.0	55.5
Av.												26,387	36,567	47,757	61,502	91,950					
726	3¼	.999	.878	.730	77.3	53.4	4.99	6.28	6.58	25.9	30.8	24,687	36,700	46,823	60,611	87,694					
727	"	.999	.876	.748	76.9	55.9	4.97	6.27	6.52	26.2	31.2	24,496	37,000	47,205	61,390	84,205					
Av.												24,591	36,850	47,014	61,000	85,949					52.3
729	3½	1.002	.910	.752	82.5	56.8	4.97	6.03	6.43	21.2	29.8	25,555	37,200	47,178	57,195	83,787					
730	"	.999	.900	.775	81.2	60.2	5.00	6.08	6.38	21.6	27.5	24,368	36,700	46,823	47,686	77,803					
Av.												24,951	36,950	47,000	57,440	80,795					52.4
731	3¾	1.000	.879	.762	77.8	58.0	4.90	6.16	6.37	25.6	30.0	24,255	36,750	46,791	60,563	80,592					
732	"	1.002	.875	.775	76.3	59.8	4.90	6.18	6.40	26.1	30.6	23,018	36,700	46,543	61,034	77,803					
Av.												23,636	36,725	46,667	60,798	79,147					50.6
733	4	1.002	.881	.751	77.3	56.2	4.90	6.18	6.43	26.1	31.2	23,082	36,600	46,417	60,039	82,618					
734	"	1.002	.603	.770	81.2	59.0	4.90	6.08	6.30	23.1	28.9	23,779	36,450	46,227	56,917	78,269					
Av.												23,430	36,525	46,322	58,478	80,443					50.6

This set of bars was rolled from piles, the dimensions of which were as follows: 1″ and 1⅛″, 5″×5″=25 square inches; from 1¼″ to 1⅞″, inclusive, 6″×6″=36 square inches; from 2″ to 2¼″, inclusive, 8″×9″=72 square inches; from 2½″ to 4″, inclusive, 8″×10″=80 square inches.

Test-pieces Nos. 705 to 712, 716, 719, 722, and 725 were released from stress at tensile limit, and retested after a rest of six months.

The remarkably high elastic limit of the bars of less than 2″ diameter exceeds even that of F, second lot.

Tension tests upon round bars of rolled iron—Continued.

Investigation—Effect of variation in amount of reduction from pile to bar, and comparison of strength of rough and turned bars. *Test-pieces*—Bars as rolled and turned cylinders. *Testing-machine*—B.

IRON F (THIRD LOT)—Continued.

Test numbers.	Diameter of bars.	Rough or turned.	Dimensions of test-pieces.										Stress in pounds at—					Excess of strength, pounds.		Ratio of elastic to tensile limit.
			Diameter.			Length.			Reduced area.		Per cent. elongation.		Elastic limit per square inch.	Tensile limit.						
			Original.	At tensile limit.	At fracture.	Original.	At tensile limit.	At fracture.	At tensile limit.	At fracture.	At tensile limit.	At fracture.		Observed.	Per square inch original area.	Per square inch tensile limit area.	Per square inch fractured area.	Rough exceeds turned.	Turned exceeds rough.	
	"		"	"	"	"	"	"												
735	¼	T	.192	.169	.159	.98	1.09	1.10	77.5	48.6	10.6	12.0	....	1,725	59,585	76,721	86,858	....	....	......
736	⅜	R	.377	.329	.284	2.44	2.85	2.94	76.2	56.8	16.9	20.6	37,858	6,000	53,763	70,579	94,712	....	....	......
737	"	R	.375	.324	.284	1.47	1.70	1.75	74.6	57.3	15.6	19.0	44,157	5,950	53,895	72,140	93,922	....	....	......
738	"	R	.374	.315	.277	1.82	2.13	2.19	70.9	54.9	16.7	20.0	38,626	6,000	54,595	76,992	99,568	....	....	......
Av.	....	.....	....	....	....	....	....	....	73.9	56.3	16.4	19.9	40,213	....	54,084	73,237	96,064	....	....	74.4
739	⅜	.....	.269	.225	.204	1.17	1.43	1.47	70.0	57.5	21.9	25.3	39,750	3,075	54,108	77,339	94,123	....	24	73.4
740	½	T	.374	.322	.276	1.55	1.89	1.98	74.1	54.4	22.3	27.9	39,126	5,800	52,775	71,226	96,941	....	....	74.2
741	⅝	R	.628	.559	.476	2.86	3.29	3.42	81.2	57.5	14.9	19.7	34,146	15,700	50,694	63,977	85,252	....	....	......
742	"	R	.624	.562	.488	2.84	3.10	3.22	79.1	61.2	*09.1	*13.5	35,971	16,600	54,284	66,908	88,770	....	....	......
743	"	R	.624	.555	.465	3.35	3.77	3.90	74.1	55.5	12.5	16.4	32,537	15,650	51,177	64,696	92,167	....	....	......
Av.	....	.....	....	....	....	....	....	....	78.1	58.1	13.7	18.1	34,218	....	52,052	65,194	88,730	621	....	65.8
744	⅝	T	.490	.425	.356	2.14	2.48	2.62	79.2	52.8	15.5	22.0	35,525	9,700	51,431	68,358	97,448	....	....	65.9
745	¾	R	.755	.658	.560	3.54	4.16	4.36	76.0	55.0	17.0	22.9	35,068	22,500	50,368	66,176	91,555	....	....	......
746	"	R	.774	.692	.599	3.48	3.90	4.09	80.0	60.0	12.2	17.4	36,291	24,800	51,647	64,610	86,234	....	....	......
747	"	R	.783	.700	.623	3.44	3.77	3.85	80.0	63.3	*09.3	*11.0	37,279	25,950	53,893	67,437	85,137	....	....	......
Av.	....	.....	....	....	....	....	....	....	78.7	59.4	14.8	20.1	36,212	....	51,969	66,074	87,642	1,693	....	69.7
748	¾	T	.480	.424	.353	1.87	2.30	2.48	78.0	54.1	23.0	26.0	35,094	9,100	50,276	64,447	92,980	....	....	70.0

* Not considered in average.

Tension tests upon round bars of rolled iron—Continued.

IRON F (THIRD LOT)—Continued.

[Comparison of strength of rough and turned bars.]

Test numbers.	Diameter of bars.	Rough or turned.	Dimensions of test-pieces.										Stress in pounds at—					Excess of strength, pounds.		Ratio of elastic to tensile limit.
			Diameter.			Length.			Reduced area.		Per cent. elongation.		Elastic limit per square inch.	Tensile limit.						
			Original.	At tensile limit.	At fracture.	Original.	At tensile limit.	At fracture.	At tensile limit.	At fracture.	At tensile limit.	At fracture.		Observed.	Per square inch original area.	Per square inch tensile limit area.	Per square inch fractured area.	Rough exceeds turned.	Turned exceeds rough.	
	"		"	"	"	"	"	"												
749	⅞	R	.882	.788	.639	3.99	4.59	4.83	79.8	52.5	15.0	21.1	30,810	30,750	50,327	63,051	95,884	....	....	......
750	"	R	.889	.792	.644	4.54	5.09	5.36	79.6	52.5	12.2	18.0	33,833	31,300	50,427	63,527	96,100	....	....	......
751	"	R	.860	.793	.650	4.16	4.68	4.88	79.6	53.5	11.2	17.4	34,965	31,900	51,393	64,588	96,142	....	....	......
Av.	....	.....	....	....	....	....	....	....	79.7	52.8	12.8	18.8	33,204	31,317	50,716	63,722	96,042	....	....	65.4
752	⅞	T	.553	.487	.420	2.44	3.01	3.09	76.6	57.5	23.2	26.6	36,115	12,100	50,374	64,949	87,300	....	1,227	70.01

The dimensions of the piles from which this set of bars were rolled were, for ⅞" to ⅝" inclusive, 4"×3½"; for ½" and ⅜", 3"×3"; for the ¼", 1½"×1½".

Tension tests upon round bars of rolled iron.

Investigation—The elimination of the variations in tensile strength, usually accompanying variations in diameter. *Test-pieces*—Bars as rolled. *Testing-machine*—A.

IRON F*x* (FIRST LOT).

Test number.	Diameter. Original.	Diameter. At fracture.	Length. Original.	Length. At fracture.	At fracture. Reduced area.	At fracture. Per cent. of elongation.	Elastic limit. Observed.	Elastic limit. Per square inch.	Tensile limit. Observed.	Tensile limit. Per square inch original area.	Tensile limit. Area fracture.	Ratio of elastic tensile limit.
	″	″	″	″								
753	1.01	.75	6.10	7.45	55.1	22.1	27,500	34,323	44,800	55,292	100,271	62.0
754	1.01	.74	6.10	7.70	53.7	26.2	28,000	34,947	45,000	56,165	104,651	62.2
755	1.01	.76	6.00	7.10	56.6	18.3	27,600	34,448	44,200	55,167	97,440	62.4
756	1.02	.76	5.25	6.50	55.5	23.8	27,500	33,656	45,700	55,929	100,749	60.2
757	1.02	.75	5.25	6.38	54.0	21.5	27,800	34,022	46,000	56,296	104,187	60.5
Av.	......	......	....	....	55.0	22.9	27,680	34,279	45,040	55,768	....	61.5
758	1.14	.80	8.00	9.80	49.3	22.5	35,600	34,867	57,000	55,827	113,387	62.5
759	1.14	.83	8.00	9.73	53.0	21.6	35,000	34,280	58,100	56,905	107,373	60.2
760	1.14	.85	8.00	9.74	55.6	21.7	36,000	35,259	57,300	56,121	100,969	62.5
761	1.14	.85	6.75	7.90	55.5	17.0	35,600	34,867	57,100	55,925	100,616	62.3
762	1.14	.85	6.75	8.18	55.5	21.2	35,300	34,140	58,600	57,394	103,259	60.0
Av.	......	......	....	....	53.8	20.8	35,500	34,682	57,620	56,434	....	61.5
763	1.26	.95	6.50	7.87	57.8	21.1	43,500	34,883	68,900	55,253	97,206	63.1
764	1.26	.93	6.50	7.85	55.4	20.7	44,000	35,284	69,600	55,814	102,459	63.2
765	1.26	.92	6.50	7.90	54.2	21.5	43,200	34,643	68,600	55,012	103,188	63.0
766	1.25	.92	6.50	8.05	54.1	23.8	42,200	34,392	67,400	54,930	101,388	62.6
767	1.25	.93	6.50	8.20	55.3	26.1	42,600	34,718	67,800	55,256	99,808	62.8
Av.	......	......	....	....	54.4	22.6	43,100	34,784	68,460	55,253	....	63.0
768	1.39	1.04	7.25	9.50	56.0	31.0	50,200	33,091	79,800	52,603	93,937	62.9
769	1.39	1.01	7.25	9.60	52.8	32.4	50,800	33,487	81,000	53,394	101,098	62.7
770	1.39	1.02	7.25	9.47	53.9	30.6	51,400	33,882	80,700	53,194	98,763	63.7
771	1.39	1.01	8.00	9.80	52.8	22.5	49,800	32,827	80,800	53,243	100,773	61.6
772	1.39	1.00	8.00	9.88	52.6	23.5	50,200	33,091	79,500	52,406	101,222	63.1
Av.	......	......	....	....	53.6	28.0	50,480	33,275	80,360	52,968	....	62.8
773	1.50	1.12	9.00	11.00	55.7	22.2	60,200	34,069	95,000	53,763	96,425	63.4
774	1.50	1.10	10.00	12.50	53.8	25.0	60,600	34,295	94,600	53,537	99,547	64.1
775	1.50	1.10	10.00	12.35	53.8	23.5	61,000	34,522	95,000	53,763	99,968	64.3
776	1.50	1.10	8.00	9.90	53.8	23.7	61,400	34,748	93,900	53,140	98,810	65.4
777	1.50	1.10	8.00	9.95	53.8	24.4	59,900	33,899	94,100	53,254	99,021	63.6
Av.	......	......	....	....	54.2	23.8	60,620	34,307	94,520	53,491	....	64.1
778	1.62	1.20	7.00	8.44	45.1	20.6	70,300	34,109	110,300	53,517	97,524	63.7
779	1.62	1.14	7.00	8.65	49.6	23.6	70,000	33,964	110,000	53,372	107,787	63.6
780	1.62	1.17	7.00	8.42	52.2	20.3	71,000	34,449	110,000	53,372	102,325	64.5
781	1.62	1.16	5.50	8.29	51.3	14.4	71,200	34,546	111,000	54,842	105,014	64.1
782	1.62	1.20	5.50	6.05	45.1	11.0	70,300	34,109	109,400	53,081	86,728	64.0
Av.	......	......	....	....	48.6	18.0	70,560	34,325	110,140	53,537	....	64.0
783	1.75	1.35	7.50	9.12	59.5	21.6	88,000	36,590	130,000	54,054	90,845	67.7
784	1.75	1.32	8.00	9.75	56.9	21.9	87,600	36,424	131,000	54,470	95,760	66.9
785	1.75	1.33	8.50	10.75	57.8	26.5	87,400	36,340	128,000	53,222	92,152	68.3
786	1.75	1.35	6.50	7.68	59.5	18.1	88,000	36,590	130,000	54,054	90,845	67.7
787	1.75	1.32	6.50	7.75	56.9	19.2	88,800	36,923	128,500	53,430	93,932	69.1
Av.	......	......	....	....	58.1	21.4	87,960	36,573	129,500	53,846	....	67.9
788	1.88	1.45	9.00	10.36	59.5	15.1	99,000	35,663	149,000	53,674	92,048	66.4
789	1.88	1.38	9.00	10.05	53.9	11.7	98,300	35,414	146,300	52,705	97,794	67.2
790	1.88	1.52	9.00	9.76	65.4	08.4	98,300	35,414	145,400	52,377	80,110	66.5
791	1.88	1.41	8.00	10.00	56.2	25.0	99,800	35,983	146,000	52,596	93,529	68.3
792	1.88	1.44	8.00	9.95	58.7	24.4	99,200	35,734	147,200	53,025	93,062	67.4
Av.	......	......	....	....	58.7	16.9	98,920	35,641	146,780	52,875	....	67.3
793	2.00	1.49	9.00	11.12	55.5	23.5	109,000	34,691	163,000	51,877	93,463	66.9
794	2.00	1.46	9.00	11.40	53.3	24.4	108,700	34,595	163,600	52,069	97,730	66.4
795	2.00	1.46	9.00	11.10	53.3	23.3	108,900	34,659	163,000	51,877	97,371	66.8
796	2.00	1.52	8.00	9.60	57.7	20.0	109,000	34,691	163,500	52,037	90,082	66.6
797	2.00	1.48	8.00	9.90	54.7	23.7	109,300	34,876	164,000	52,196	95,348	66.6
Av.	......	......	....	....	54.9	23.0	108,980	34,702	163,420	52,011	....	66.6

Tension tests upou round bars of rolled iron—Continued.

IRON F *x* (SECOND LOT).

Test number.	Diameter.		Length.		At fracture.		Elastic limit.		Tensile limit.			Ratio of elastic tensile limit.
	Original.	At fracture.	Original.	At fracture.	Reduced area.	Per cent. of elongation.	Observed.	Per square inch.	Observed.	Per square inch original area.	Area fracture.	
	"	"	"	"								
798	1.00	.73	4.50	5.25	53.3	16.6	27,900	36,796	44,600	56,786	106,571	62.6
799	1.00	.75	4.50	5.38	56.3	19.5	28,300	37,318	45,000	57,308	101,856	60.0
800	1.00	.72	4.50	5.64	51.8	25.3	27,700	36,541	44,200	56,277	108,572	62.7
Av.					**53.8**	**20.5**	**27,967**	**36,885**	**44,450**	**56,790**		**62.3**
801	1.12	.80	6.00	7.12	51.0	18.7	36,200	36,743	54,500	55,318	108,402	66.4
802	1.12	.82	6.00	7.17	53.6	19.5	37,100	37,657	55,500	56,333	105,093	66.8
803	1.12	.83	6.00	7.05	54.9	17.5	36,800	37,352	55,300	56,130	102,199	66.5
Av.					**53.2**	**18.6**	**36,700**	**37,250**	**55,100**	**55,927**		**66.6**
804	1.24	.90	7.00	8.50	52.7	21.4	46,500	38,493	66,000	54,635	103,740	70.5
805	1.24	.93	7.00	8.28	56.2	18.3	47,000	38,907	67,500	55,877	99,367	69.6
806	1.24	.92	7.00	8.42	55.0	20.3	46,400	38,410	66,300	54,884	99,729	70.0
Av.					**52.8**	**20.0**	**46,633**	**38,603**	**66,600**	**55,132**		**70.0**
807	1.37	1.00	8.00	9.95	53.3	34.4	52,600	35,685	77,500	52,578	98,675	67.9
808	1.37	1.00	8.00	9.91	53.3	23.9	53,100	36,024	75,000	50,882	95,492	70.8
809	1.37	1.01	8.00	9.06	54.4	24.5	53,100	36,024	76.500	51,900	95,413	69.4
Av.					**53.7**	**24.3**	**52,933**	**35,911**	**76,333**	**51,487**		**69.4**
810	1.50	1.06	10.00	12.54	49.9	25.4	61,500	34,804	90,900	51,443	103,002	67.6
811	1.50	1.07	10.00	12.43	50.9	24.3	62,200	35,200	91,400	51,726	101,646	68.0
812	1.50	1.03	10.00	12.67	49.9	26.7	61,400	34,748	90,600	51,273	102,662	67.8
Av.					**50.2**	**25.5**	**61,700**	**34,917**	**90,967**	**51,481**		**67.8**
813	1.61	1.21	7.25	8.80	56.5	21.4	73,000	35,854	109,000	53,536	94,782	67.0
814	1.61	1.18	7.25	9.13	53.7	25.9	73,200	35,952	109,500	53,782	100,091	66.8
815	1.61	1.24	7.25	8.94	59.3	23.3	72,900	35,805	107,900	52,996	89,321	67.5
Av.					**56.5**	**23.5**	**73,033**	**35,870**	**108,800**	**53,438**		**67.1**
816	1.71	1.24	9.00	11.16	52.6	24.0	80,600	35,089	119,000	51,806	98,510	67.7
817	1.71	1.25	8.00	9.99	53.4	24.9	81,000	35,263	120,500	52,459	98,207	67.2
818	1.71	1.24	8.00	10.17	52.6	27.1	82,000	35,698	121,000	52,677	100,165	67.7
Av.					**52.8**	**25.3**	**81,200**	**35,350**	**120,167**	**52,314**		**67.5**
819	1.86	1.38	9.00	11.16	55.0	24.0	93,100	34,265	140,000	51,527	93,582	66.5
820	1.86	1.35	9.00	11.30	52.7	25.5	91,800	33,787	138,000	50,791	96,436	66.5
821	1.86	1.40	9.00	11.09	56.6	23.2	92,000	33,860	139,000	51,159	90,318	66.2
Av.					**54.7**	**24.2**	**92,300**	**33,970**	**139,000**	**51,159**		**66.4**
822	1.99	1.42	10.00	12.39	50.9	23.9	100,000	32,154	155,000	49,839	97,853	64.5
823	1.99	1.44	10.00	12.30	52.4	23.0	103,000	33,119	155,500	50,000	95,457	66.2
824	1.99	1.43	10.00	12.27	51.6	22.7	103,500	33,279	156,000	50,160	97,135	66.3
Av.					**51.6**	**23.2**	**102,167**	**36,184**	**155,500**	**50,000**		**65.7**

IRON F *x* (THIRD LOT).

Test number.	Diameter. Original.	Diameter. At fracture.	Length. Original.	Length. At fracture.	Reduced area.	Per cent. of elongation.	Elastic limit. Observed.	Elastic limit. Per square inch.	Tensile limit. Observed.	Tensile limit. Per square inch original area.	Area fracture.	Ratio of elastic tensile limit.
825	1.00	.75	5.00	5.75	56.3	15.0	28,000	35,650	42,500	54,112	96,197	65.9
826	1.00	.74	5.00	5.78	54.7	15.6	29,000	36,923	42,200	53,718	98,139	68.7
Av.					**55.5**	**15.3**	**28.500**	**36,336**	**42,350**	**53,915**		**67.3**
827	1.13	.82	6.00	7.19	55.6	19.8	35,000	34,895	55,000	54,853	104,146	63.6
828	1.13	.81	6.00	6.95	54.2	15.8	34,600	34,496	54,600	54,436	105,957	63.4
Av.					**54.9**	**17.8**	**34,800**	**34,695**	**54,800**	**54,644**		**63.5**
829	1.26	.91	7.00	8.63	52.2	23.3	42,600	34,162	66,000	52,927	101,476	64.5
830	1.26	.90	7.00	8.63	51.0	23.3	41,000	32,879	66,800	53,568	104,998	61.4
Av.					**51.6**	**23.3**	**41,800**	**32,520**	**66,400**	**53,247**		**62.9**
831	1.39	.97	8.50	10.72	42.1	26.1	52,000	34,275	79,000	52,073	106,901	65.8
832	1.39	1.00	7.50	9.10	51.7	21.3	53,000	34,937	81,000	53,394	103,132	65.4
Av.					**46.9**	**23.7**	**52,500**	**34,606**	**80,000**	**52,733**		**65.6**
833	1.51	1.10	9.00	11.37	53.0	26.3	62,800	35,004	95,000	53,043	99,968	66.1
834	1.51	1.10	9.00	10.76	53.0	19.6	62,000	34,617	94,200	52,596	99,126	65.8
Av.					**53.0**	**22.9**	**62,400**	**34,840**	**94,600**	**52,819**		**65.9**

Tension tests upon round bars of rolled iron—Continued.

IRON F*x* (THIRD LOT)—Continued.

Test number.	Diameter.		Length.		At fracture.		Elastic limit.		Tensile limit.			Ratio of elastic to tensile limit.
	Original.	At fracture.	Original.	At fracture.	Reduced area.	Per cent. of elongation.	Observed.	Per square inch.	Original.	Per square inch original area.	Area fracture.	
	″	″	″	″								
835	1.63	1.18	7.00	8.67	52.4	23.9	60,600	33,061	110,600	52,994	101,096	62.4
836	1.63	1.22	7.00	8.56	56.0	22.8	71,000	34,020	112,000	53,665	95,808	63.4
Av.	......	......	......	......	**54.2**	**23.1**	**70,000**	**33,540**	**111,300**	**53,329**	....	**62.9**
837	1.74	1.30	10.00	12.27	55.8	22.7	80,000	34,903	126,000	53,112	94,951	63.5
838	1.74	1.27	10.00	12.42	53.4	24.2	82,000	35,744	126,200	53,196	99,605	66.0
Av.	......	......	......	......	**54.6**	**23.4**	**81,000**	**35,323**	**126,100**	**53,154**	....	**64.9**
839	1.87	1.40	10.00	12.15	56.0	21.5	95,400	34,741	148,000	53,918	96,166	94.0
840	1.87	1.36	10.00	12.52	52.9	25.2	97,000	35,324	145,000	52,804	99,793	66.9
Av.	......	......	......	......	**54.4**	**23.3**	**96,200**	**35,032**	**146,500**	**53,361**	....	**65.7**
841	2.00	1.48	10.50	13.28	54.7	26.5	103,000	32,781	158,000	50,286	91,860	65.2
842	......	1.48	10.50	12.96	54.7	23.4	106,000	33,736	161,000	51,241	93,604	65.8
Av.	......	......	......	......	**54.7**	**24.9**	**104,500**	**33,172**	**159,500**	**50,763**	....	**65.5**

Investigation—Careful test for elastic limit of iron F*x*, third lot. *Test-pieces*—Turned cylinders and bars as rolled. *Testing-machines*—B.

IRON F*x* (SECOND AND THIRD LOTS).

[Test for limit of elasticity.]

Test numbers.	Diameter of bar.	Dimensions of test-pieces.						Stress in pounds at—				Ratio between elastic and tensile limit.
		Diameter.			Length.			Elastic limit.		Tensile limit.		
		Original.	At elastic limit.	At fracture.	Original.	At elastic limit.	At fracture.	Observed.	Per square inch.	Observed.	Per square inch.	
	″	″	″	″	″	″	″					
844	1¼	.500	.495	.359	2.500	2.509	3.268	7,375	37,551	10,050	51,171	73.3
845	1	.501	.500	.350	2.500	2.507	3.298	6,937	35,195	10,350	52,511	67.0

Measurements were taken at every 50 pounds increase on 1¼″, and every 25 pounds on 1″ bar.
No change of form at 7,300 pounds on the first, or at 6,925 pounds on the second.

Tension tests upon round bars of rolled iron—Continued.

Testing-machine—A.

IRON F *x* (SECOND AND THIRD LOTS)—Continued.

[Tests to determine variation in percentage of elongation, due to variation in length of test-pieces.]

Test number.	Diameter of bar.	Dimensions of test-pieces.						Stress in pounds at—				Per cent. of elongation at fracture.
		Diameter.			Length.			Elastic limit.		Tensile limit.		
		Original.	At elastic limit.	At fracture.	Original.	At elastic limit.	At fracture.	Observed.	Per square inch.	Observed.	Per square inch.	
	″	″		″	″		″					
846	1¾	1.73	......	1.21	75.0	....	89.00	76,900	32,709	117,100	50,021	18.66
447	"	1.73	......	1.21	20.0	....	24.36	80,500	34,240	118,600	50,446	21.80
448	"	1.73	......	1.24	10.0	....	12.22	80,000	34,028	121,000	51,467	23.20

Unless caused by unknown reasons, the extreme variation in per cent. of elongation, due to variation in *length* of test-piece was 3″. 54.

Tensile strength per square inch of three lots each of irons F and Fx.

[Abstract from preceding records.]

Diameter of bars.	Iron F.			Iron Fx.		
	First lot.	Second lot.	Third lot.	First lot.	Second lot.	Third lot.
″						
1	51,262	52,819	51,128	55,768	56,790	53,915
1⅛	53,850	52,267	50,149	56,484	55,927	54,644
1¼	52,970	52,620	52,279	55,258	55,182	53,247
1⅜	51,296	52,587	52,339	52,968	51,487	52,738
1½	51,994	51,456	50,820	53,491	51,481	53,819
1⅝	52,165	50,970	50,529	53,587	53,438	53,329
1¾	50,690	49,738	50,547	53,846	52,814	53,154
1⅞	51,039	49,061	49,744	52,875	51,159	53,361
2¼	48,956	47,569	47,872	52,011	50,000	50,763
Av...	51,580	51,004	50,600	54,020	53,081	53,108

The history of the process of manufacture of the above set of bars—dimensions of piles, &c.—together with a discussion of the results of the tests are given in the paper on the bar "effect of differences in the amount of reduction by the rolls," pages 33 to 45.

Tension tests upon round bars of rolled iron—Continued.

Investigation—Character as adapted for chain cables. *Test-pieces*—Bars as rolled. *Testing-machine*—A.

IRON K.

Test number.	Diameter of bar.	Dimensions of test-pieces.						Stress in pounds at—				Ratio of elastic to tensile limit.
		Diameter.		Length.		At fracture.		Elastic limit per square inch.	Tensile limit.			
		Original.	At fracture.	Original.	At fracture.	Reduced area.	Per cent. of elongation.		Observed.	Per square inch original area.	Area fracture.	
	"	"	"	"	"							
849	1⅛	1.125	.875	13.50	16.12	60.5	19.4	36,700	59,136	59,492	98,343	61.6
850	"	1.125	.875	13.50	16.25	60.5	20.3	36,700	60,096	60,458	99,940	60.7
851	"	1.125	.875	13.50	16.12	60.5	19.4	38,631	61,056	61,424	102,148	62.8
Av.	......	......	......	......	......	60.5	......	37,344	60,096	60,458	100,144	61.7
852	1¼	1.250	1.000	16.00	18.87	64.0	18.0	37,551	73,920	60,244	94,117	62.3
853	"	1.250	1.062	16.00	18.56	72.3	16.0	35,452	72,000	58,679	81,264	60.0
Av.	......	......	......	......	......	68.1	......	36,501	72,960	59,461	87,690	61.1
854	1⅜	1.375	1.062	15.75	19.12	60.0	21.4	31,084	80,640	54,303	91,015	57.1
855	"	1.375	1.000	15.75	19.50	52.9	23.8	31,084	85,056	57,277	108,296	54.1
Av.	......	......	......	......	......	56.4	......	31,084	82,848	55,790	99,655	55.6
856	1½	1.500	1.125	19.00	23.37	69.5	17.7	32,597	102,720	58,132	103,340	56.0
857	"	1.500	1.125	19.00	23.12	69.5	21.7	34,227	99,840	56,502	100,402	60.5
Av.	......	......	......	......	......	69.5	......	33,412	101,280	57,317	101,871	58.2
858	1⅝	1.625	1.187	19.00	22.87	53.4	20.7	......	119,612	57,674	108,048	......
859	"	1.625	1.187	19.00	21.87	53.4	15.1	34,717	114,240	55,132	103,197	63.0
860	"	1.625	1.198	18.00	21.72	54.4	20.6	35,180	120,000	57,862	106,194	60.8
861	"	1.625	1.250	18.00	21.47	59.2	19.2	35,180	120,000	57,862	97,799	60.8
Av.	......	......	......	......	......	55.1	......	35,026	118,463	57,132	103,809	61.5
862	1$\frac{11}{16}$	1.710	1.280	9.00	9.90	56.0	10.0	38,310	130,000	56,595	101,010	67.7
863	1¾	1.750	1.500	9.00	22.85	73.0	17.6	33,124	139,200	57,874	78,777	57.2
864	1$\frac{13}{16}$	1.830	1.350	11.56	14.08	54.5	21.8	32,486	148,800	56,577	103,963	57.0
865	1⅞	1.875	1.440	19.50	23.90	59.0	18.4	30,944	153,600	55,630	94,814	55.6
866	"	1.875	1.410	18.00	21.97	57.0	22.0	31,118	154,560	55,977	99,693	......
Av.	......	......	......	......	......	58.0	20.2	31,031	154,080	55,803	97,003	......
867	2	2.030	1.640	18.00	20.40	......	18.8	31,441	194,880	60,213	92,255	52.2
868	"	2.040	1.540	19.00	22.88	......	17.8	30,839	188,160	57,567	101,708	53.5
Av.	......	......	......	......	......	......	15.5	31,140	191,520	58,890	96,981	......

Tension tests upon round bars of rolled iron—Continued.

IRON K (1″ BARS) AND D (1″ BAR).

Bar.		Dimensions of test-pieces.						Stress in pounds at elastic limit.	Rough exceeds turned.	Turned exceeds rough.
		Diameter.		Length.		At fracture.				
Test number.	Iron, rough or turned.	Original.	At fracture.	Original.	At fracture.	Reduced area.	Per cent. of elongation.			
		″	″	″						
869	K R	.997	.776	3.95	....	59.8	21.5	62,444	....	....
870	K R	.998	.770	3.95	....	59.6	21.0	61,900	....	....
871	K R	.999	.762	3.95	....	58.0	21.6	62,465	....	....
Av.	....	....	....	....	....	59.2	21.2	62,269	1,733	....
872	K T	.900	.694	3.56	....	59.5	23.3	59,439	....	....
873	K T	.900	.706	3.56	....	61.9	20.8	61,930	....	....
874	K T	.900	.698	3.56	....	60.1	21.6	60,240	....	....
Av.	....	....	....	....	....	60.5	20.9	60,536	....	....
875	K R	.998	.764	3.97	....	57.8	22.2	62,100	....	....
876	K R	.992	.776	3.92	....	61.3	23.2	62,360	....	....
877	K R	.996	.754	3.89	....	57.3	22.1	61,609	....	....
878	K R	.993	.768	3.94	....	59.9	23.7	61,711	....	....
Av.	....	....	....	....	....	59.1	22.8	61,949	126	....
879	K T	.898	.691	3.55	....	59.2	23.9	61,067	....	....
880	K T	.893	.689	3.50	....	59.3	18.3	62,747	....	....
881	K T	.900	.684	3.55	....	59.6	26.5	61,656	....	....
Av.	....	....	....	....	....	59.4	22.9	61,823	....	....
882	D R	1.02	.695	4.40	....	46.1	28.4	52,605	....	....
883	D R	1.01	.675	4.45	....	45.1	20.2	52,806	....	....
884	D R	1.02	.688	4.42	....	45.5	24.3	52,710	....	....
885	D R	1.01	.723	4.02	....	50.8	31.6	55,390	....	....
Av.	....	....	....	....	....	46.8	26.1	53,400	992	....
886	D T	.969	.667	3.89	....	47.5	29.0	52,712	....	....
887	D T	.970	.671	3.75	....	48.0	26.6	51,623	....	....
888	D T	.966	.667	3.65	....	47,7	30.8	51,848	....	....
889	D T	.970	.650	3.62	....	45.0	31.7	53,450	....	....
Av.	....	....	....	....	....	47.0	29.5	52,408	....	....

Irons K and D were representatives of extreme contrasting types of very refined and pure iron, the first a Pennsylvania and second Massachusetts production—the latter being rivet iron and the former the only iron tested which would come up to the government standard of 60,000 pounds per square inch. Their record has been placed under one heading for contrast.

Tension tests upon round bars of rolled iron—Continued.

Investigation—Elevation of limit of stress of bars with and without skin. *Test-pieces*—Bars as rolled and as slightly reduced. *Testing-machine*—B.

IRON K (1″ BAR).

Bar.		Dimensions of test-pieces.										Stress in pounds per square inch at—						Rough exceeds turned, pounds.	Ratio elastic to tensile limit.
		Diameter.			Length.			Reduced area.		Per cent. of elongation.			Tensile limit.			Gain by rest.			
Test number.	Rough or turned.	Original.	At tensile limit.	At fracture.	Original.	At tensile limit.	At fracture.	At tensile limit.	At fracture.	At tensile limit.	At fracture.	Elastic limit.	First test.	Second test.	Period of rest.	Pounds.	Per cent.		
		″	″	″	″	″	″												
890	R	1.005	.893	.764	4.14	4.68	4.89	78.6	57.4	11.8	18.1	38,029	56,571	61,333	48 hours	4,762	......	......	......
891	R	.986	.864	.775	4.36	4.95	5.20	76.8	61.8	13.5	19.2	39,289	58,293	62,341	48 hours	4,948	......	......	......
892	R	1.000	.879	.764	4.24	4.80	5.06	77.8	59.9	13.2	19.3	38,356	57,248	61,752	48 hours	4,505	......	......	......
Av.	......	......	......	......	......	......	......	77.5	59.7	12.8	18.9	38,558	57,371	62,109	48 hours	4,738	8.2	284	67.1
893	T	.797	.705	.598	3.58	4.18	4.39	78.3	55.4	16.7	22.6	35,078	56,852	61,887	48 hours	5,035	......	......	......
894	T	.797	.715	.586	3.71	4.30	4.56	80.5	54.1	16.7	22.9	35,579	56,950	62,088	48 hours	5,138	......	......	......
895	T	.797	.715	.613	3.65	4.14	4.36	80.5	59.2	13.4	19.4	36,080	57,459	62,438	48 hours	4,979	......	......	......
Av.	......	......	......	......	......	......	......	79.8	56.2	15.6	21.6	35,576	57,087	62,138	48 hours	5,051	8.9	......	61.7

Tension tests upon round bars of rolled iron—Continued.

Investigation—Character as chain iron, and effect on tensile strength of variation in amount of reduction by rolls. *Test-pieces*—Bars as rolled. *Testing-machine*—A.

IRON N.

[Bars purchased for purpose of test.]

Test number.	Diameter of bar.	Dimensions of test-pieces.						Stress in pounds at—					Remarks.	Gain or loss in tensile limit, pounds.
		Diameter.		Length.		At fracture.		Elastic limit per square inch.	Tensile limit.					
		Original.	At fracture.	Original.	At fracture.	Reduced area.	Per cent. elongation.		Observed.	Per square inch original area.	Per square inch fractured area.	Ratio of elastic to tensile limit.		
	"	"	"	"	"									
896	1⅛	1.13	.89	7.0	8.28	62.1	18.8	81,968	56,000	55,994	90,017	57.1	Bright gray fiber	
897	"	1.13	.85	7.0	8.76	56.6	25.1	82,567	56,400	56,343	99,383	57.8	do	
Av.						59.3	21.7	82,267	56,200	56,143	94,700	57.4		
898	1¼	1.25	1.01	7.0	8.44	59.2	20.6	83,414	69,600	56,723	81,930	57.4	Bright gray fiber, with fine bright spots	
899	"	1.25	.98	7.0	8.65	61.5	23.6	83,088	69,000	56,234	91,475	58.8	do	+ 335
Av.						60.3	22.1	83,251	69,300	56,478	86,702	58.1		
900	1⅜	1.38	1.03	8.0	10.12	55.7	26.5	83,823	80,400	53,743	96,495	62.9	Gray fiber	
901	"	1.38	1.08	8.0	9.80	61.2	22.5	83,422	82,000	54,812	89,510	61.0	do	−2.709
Av.						58.4	24.5	83,622	81,200	54,277	93,002	62.0		
902	1½	1.40	1.15	9.0	10.93	59.6	21.4	84,977	92,800	53,211	89,316	65.7	Dark and seamy	
903	"	1.40	1.15	9.0	11.30	59.6	25.5	34,403	94,000	53,899	90,473	63.8	do	
Av.						59.6	23.4	84,690	93,400	53,555	89,984	64.7		− 722
904	1⅝	1.64	1.28	8.7	10.50	60.9	20.6	85,984	119,000	56,344	92,463	63.8	Dark fiber, with coarse bright spots	
905	"	1.64	1.25	8.7	10.88	58.1	24.9	85,795	119,000	56,344	96,984	63.5	do	
Av.						59.5	22.7		119,000	56,344	94,728	63.6		+2.789
906	1¾	1.73	1.47	9.0	10.89	72.2	21.0	84,368	130,000	55,295	76,605	62.1	Bright and dark in layers	
907	"	1.73	1.39	9.0	10.93	64.5	21.4	84,198	128,700	54,742	84,838	62.5	do	
Av.						68.3	21.2	84,283	129,350	55,018	80,721	62.3		−1.326

908	1⅞	1.87	1.50	9.0	11.00	64.3	22.2	33,357	148,800	54,004	83,927	61.8	Bright, coarse, and crystalline	−1.014
909	"	1.87	1.80	9.0	9.68	92.7	18.7	33,867	*132,000	48,070	51,866	70.4	......do	
Av.							20.4	33,610						
910	2	2.01		9.0	10.01		11.2	32,461	165,400	52,127		62.2	Bright, coarse, and crystalline; broke close to head.	−1.877
911	"	2.01		9.0	9.56		06.3		163,000	51,870		63.1	......do	
Av.							08.7		164,200	51,748		62.6		

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* The piles from which these bars were rolled were from sizes 1⅛″ to 1⅞″, inclusive, of 15 square inch, the remainder of 27 square inch area. This slight work showed on the larger sizes by the pieces breaking with but slight change of form. Under impact, the larger bars were very brittle.

Tension tests upon round bars of rolled iron—Continued.

Investigation—Character as adapted for chain cables. *Test-pieces*—Bars as rolled. *Testing-machine*—A.

IRON O.

		Dimensions of test-pieces.						Stress in pounds at—				
		Diameter.		Length.		At fracture.			Tensile limit.			
Test number.	Diameter of bar.	Original.	At fracture.	Original.	At fracture.	Reduced area.	Per cent. of elongation.	Elastic limit per square inch.	Observed.	Per square inch original area.	Per square inch fractured area.	Ratio of elastic to tensile limit.
	″	″	″	″	″	″	″					
912	1	1.01	0.71	5.00	5.75	49.4	16.2	37,415	46,000	57,363	116,168	65.2
913	1⅛	1.10	.75	6.00	7.38	46.5	23.0	32,410	50,400	53,035	114,050	61.1
914	1¼	1.25	.81	8.00	9.90	48.0	23.7	30,078	61,400	50,040	116,265	60.1
915	1⅜	1.35	.87	9.00	11.48	41.5	27.5	34,940	72,400	50,594	121,783	69.0
916	1½	1.51	1.00	10.00	12.73	43.7	27.3	32,312	91,400	50,919	116,373	63.4
917	1⅝	1.62	1.12	8.00	9.77	47.8	22.1	34,012	108,000	52,401	109,632	64.9
918	1¾	1.72	1.17	10.00	12.38	46.3	23.8	32,271	116,500	50,120	108,372	64.3
919	1⅞	1.86	1.25	10.00	12.40	45.2	24.0	30,842	129,000	47,478	105,134	65.0
920	2	2.00	1.40	11.00	13.82	48.9	25.6	31,418	151,600	48,249	98,505	65.1

This is a very fine quality charcoal bloom iron, entirely too ductile for chain-cable manufacture. It was, however, thought desirable to procure the record as cable of iron of this character, for sake of contrast with that of such iron as N.

Investigation—Character as chain cable,—variation in tensile strength accompanying variation in diameter, &c. *Test-pieces*—Bars as rolled. *Testing-machine*—A.

IRON P (FIRST, SECOND, AND THIRD LOTS).

FIRST LOT, 1875.

		Diameter of test-pieces.						Stress in pounds at—					
		Diameter.		Length.		At fracture.			Tensile limit.				
Test number.	Diameter of bar.	Original.	At fracture.	Original.	At fracture.	Reduced area.	Per cent. of elongation.	Elastic limit per square inch.	Observed.	Per square inch original area.	Per square inch fractured area.	Ratio of elastic to tensile limit.	Gain or loss per square inch for each change in diameter ⅛″.
	″	″	″	″	″								
921	1¼	1.27	.80	6.7	8.82	40.0	81.5	35,596	70,704	55,782	....	61.4	....
922	1⅜	1.38	.86	7.0	9.07	39.0	29.6	30,802	78,624	52,550	135,341	58.6	....
923	1$\frac{7}{16}$	1.46	......	......	......	......	......	....	89,300	53,345	....	......	....
924	1½	1.52	.95	8.0	10.24	39.1	28.0	29,630	95,904	52,865	135,304	56.0	....
925	2	2.02	1.40	10.0	12.40	51.0	24.0	29,959	159,849	49,872	98,121	63.0	....

Tensile tests upon round bars of rolled iron—Continued.

IRON P (FIRST, SECOND, AND THIRD LOTS)—Continued.

SECOND LOT, 1876.

Test number.	Diameter of bar.	Diameter of test-pieces.						Stress in pounds at—				Ratio of elastic to tensile limit.	Gain or loss per square inch for each change in diameter ⅛″ (pounds).
		Diameter.		Length.		At fracture.		Elastic limit per square inch.	Tensile limit.				
		Original.	At fracture.	Original.	At fracture.	Reduced area.	Per cent. of elongation.		Observed.	Per square inch original area.	Per square inch fractured area.		
	″	″	″	″	″								
926	1	.99	.94	4.25	4.67	90.2	.9	38,971	48,000	55,858	....	69.8	....
927	"	.99	.73	4.25	5.03	54.4	18.8	39,489	46,000	59,755	109,916	66.1	....
Av.	....	......	......	......	....	....	......	**39,230**	**44,500**	**57,807**	....	**67.9**	....
928	1⅛	1.12	.82	6.00	7.20	52.6	20.0	41,006	56,000	56,840	124,976	72.1	....
929	"	1.12	.81	6.00	7.06	52.3	17.7	41,615	57,000	57,739	130,021	71.9	....
Av.	....	......	......	......	....	**53.0**	**18.9**	**41,311**	**56,500**	**57.289**	....	**72.0**	— .518
930	1¼	1.28	.91	7.00	8.78	50.5	25.4	37,218	78,000	56,721	112,238	65.6	....
931	"	1.28	.87	7.00	8.67	46.2	23.9	36,519	73,400	57,031	123,465	64.0	....
Av.	....	......	......	......	....	**48.3**	**24.6**	**36,868**	**73,200**	**56,876**	....	**64.8**	— .418
932	1⅜	1.40	.95	8.00	10.05	46.0	25.6	33,788	85,000	55,230	119,921	61.2	....
933	"	1.40	.97	8.00	9.90	46.8	23.7	37,737	85,000	55,230	115,029	64.0	....
Av.	....	......	......	......	....	**46.4**	**24.6**	**35,762**	**85,000**	**55,230**	....	**62.9**	—1.646
934	1½	1.52	1.08	10.00	12.22	50.5	22.2	33,057	97,400	58,664	106,320	61.6	....
935	"	1.52	1.10	10.00	12.40	52.3	24.0	33,233	99,200	54,655	104,388	61.8	....
Av.	....	......	......	......	....	**51.4**	**23.1**	**33,140**	**98,300**	**54,159**	....	**61.7**	—1.071
936	1⅝	1.64	1.16	8.00	8.70	**50.0**	**1.0**	**33,522**	**117,500**	**55,634**	**111,163**	**60.2**	+1.475
937	1¾	1.77	1.34	9.00	11.31	57.3	25.7	33,238	132,400	53,799	93,900	61.8	....
938	"	1.77	1.30	9.00	10.98	53.9	22.0	33,726	127,700	51,889	96,233	65.0	....
Av.	....	......	......	......	....	**55.6**	**23.8**	**33,842**	**130,050**	**52,844**	....	**63.4**	—2.790
939	1⅞	1.88	1.28	10.00	12.56	46.4	25.6	32,420	143,800	51,801	93,900	61.8	....
940	"	1.88	1.30	10.00	12.30	47.8	23.0	32,204	146,600	52,809	96,233	65.0	....
Av.	....	......	......	......	....	**47.1**	**24.3**	**32,312**	**145,200**	**52,305**	....	**63.4**	— .539
941	2	2.01	1.28	11.00	14.20	40.6	29.1	31,678	161,400	50,866	125,310	62.8	....
942	"	2.01	1.29	11.00	14.22	41.2	29.3	32,083	161,200	50,803	123,335	63.1	....
Av.	....	......	......	......	....	**40.9**	**29.2**	**31,878**	**161,300**	**50,834**	....	**62.7**	—1.471

THIRD LOT (P*x*).

943	1¼	1.26	.92	7.50	8.96	53.3	19.5	34,482	70,500	56,535	106,046	61.0	....
944	"	1.26	.95	7.50	9.08	56.8	21.0	33,360	70,000	56,134	98,758	58.1	....
Av.	....	......	......	......	....	**55.1**	**20.2**	**33,921**	**70,250**	**56,334**	**102,402**	**59.5**	....
945	1½	1.51	1.15	7.50	9.17	58.0	22.3	34,617	97,800	54,606	94,129	63.9	....
946	"	1.51	1.15	9.00	11.07	58.0	23.0	....	96,900	54,103	93,262	64.0	....
Av.	....	......	......	......	....	**58.0**	**22.6**	**34,617**	**97,350**	**54,354**	**93,695**	**64.0**	—1.980
947	1⅝	1.64	1.12	7.00	8.85	46.7	26.4	33,143	115,000	54,455	116,727	60.9	....
948	"	1.64	1.08	7.00	8.78	43.4	25.4	33,712	116,000	54,924	126,723	61.4	....
Av.	....	......	......	......	....	**45.1**	**25.9**	**33,427**	**115,500**	**54,689**	**121,675**	**66.1**	+ .335
949	1¾	1.76	1.32	9.00	11.50	56.2	22.8	33,703	131,600	54,089	96,199	62.3	....
950	"	1.76	1.32	9.00	11.22	56.2	24.7	34,114	132,200	54,336	96,637	62.8	....
Av.	....	......	......	......	....	**56.2**	**23.7**	**33,908**	**131,900**	**54,212**	**96,418**	**62.5**	— .477
951	1⅞	1.87	1.32	10.00	12.84	49.8	28.4	32,046	142,400	51,860	104,093	......	....
952	"	1.87	1.33	10.00	12.71	50.6	27.1	32,477	141,600	51,665	101,943	......	....
Av.	....	......	......	......	....	**50.2**	**27.7**	**32,261**	**142,000**	**51,762**	**103,018**	**62.3**	—2.450

Tensile tests upon round bars of rolled iron—Continued.

Investigation—Tests preliminary to receipt of chain iron. *Test-pieces*—Chain bolts in natural state. *Testing-machine*—A.

IRON P 1$\frac{5}{16}$ (CHAIN BOLTS).

Test number.	Dimensions of test-pieces.						Stress in pounds at—				Ratio of elastic to tensile limit.	Number of pieces tested.
	Diameter.		Length.		At fracture.		Elastic limit.	Tensile limit.				
								Observed.	Per square inch original area.	Per square inch fractured area.		
	″	″	″	″								
953 to 962	1.32	1.00	8.25	10.0	57.4	20.0	....	72,740	53,172	92,615	......	10
963 to 972	1.32	.98	8.30	9.9	55.1	19.3	....	73,560	53,772	97,534	......	10
973 to 982	1.32	1.01	8.25	9.9	58.3	19.6	....	74,190	54,232	92,598	......	10
983 to 992	1.32	1.00	8.30	9.8	57.4	18.0	....	72,640	53,100	92,487	......	10
993 to 1002	1.32	.98	8.33	9.6	55.1	19.4	....	74,120	54,181	98,263	......	10
1003 to 1012	1.32	1.01	8.30	9.7	58.3	16.5	....	75,560	55,234	94,309	......	10
1013 to 1022	1.32	.97	8.30	10.0	54.0	20.1	....	76,540	55,950	103,572	......	10
1023 to 1032	1.32	.99	8.36	10.1	56.8	20.4	....	75,890	55,475	97,308	......	10
1033 to 1042	1.31	.97	8.56	10.2	51.8	19.1	....	75,240	55,816	101,813	......	10
Av...	....	......	......	......	55.0	19.1	....	74,490	54,548	....	......	......
1043	1.31	.96	8.25	10.1	52.9	21.9	36,111	72,400	52,908	100,027	......	1
1044	1.31	.98	8.25	10.0	56.0	21.7	34,781	72,800	54,014	96,518	......	1
1045	1.31	.94	8.25	10.1	51.5	22.3	36,646	73,200	54,310	105,475	......	1
1046	1.31	.96	8.25	9.9	53.7	19.6	36,053	73,000	54,162	100,886	......	1
Av...	....	......	......	......	52.8	21.4	35,898	72,850	53,848	....	66.6	......

Of the above tests ninety were made by the board of officers appointed by the Equipment Bureau to inspect chain-iron delivered as samples and under contract, and the record has, by permission of the Chief of that bureau, been incorporated in this report.

No tests having been made for elastic limit, the chairmen of these committees obtained permission to make the tests 1043 to 1046, inclusive; also to make and test from the iron a set of chain links whose record is given on page 188, no tests in this form appearing upon the records of the navy-yard.

Tension tests upon round bars of rolled iron—Continued.

Investigation—Examination of chain iron delivered. *Test-pieces*—Chain bolts. *Testing-machine*—A.

IRON M.

Test number.	Diameter of bar.	Dimensions of test-pieces.						Stress in pounds at—				Ratio of elastic to tensile limit.	Number of tests in averages.	Date of testing.
		Diameter.		Length.		At fracture.		Elastic limit per square inch.	Tensile limit.					
		Original.	At fracture.	Original.	At fracture.	Reduced area.	Per cent. of elongation.		Observed.	Per square inch original area.	Per square inch fractured area.			
	″	″	″	″	″									
1047 to 1066	1¼	1.24	.98	....	....	62.2	....	....	64,285	53,022	85,273	....	20	Oct., 1875.
1067 to 1086	"	1.24	1.02	....	....	66.5	....	....	68,850	54,090	81,434	....	20	Oct., 1875.
1087 to 1106	"	1.25	.98	....	....	61.2	....	....	65,960	53,752	88,015	....	20	Nov., 1875.
Av ..	....	....	....	....	....	63.3	....	....	66,365	53,621	84,907	....	60	
1107 to 1134	"	1.37	1.10	7.00	8.52	64.1	21.7	35,820	80,693	54,373	84,917	65.8	28	Feb., 1876.
1135 to 1182	1⅜	1.37	1.07	7.70	9.20	63.0	19.9	37,548	86,862	58,926	95,287	63.6	48	Mar., 1876.
1183 to 1186	"	1.37	1.07	8.50	10.21	60.8	19.6	35,379	78,150	53,016	86,817	66.8	4	May, 1876.
1187 to 1221	"	1.39	1.12	8.00	9.39	65.5	18.9	38,578	87,496	57,649	88,288	66.9	35	Aug., 1876.
Av ..	....	....	....	....	....	63.1	20.9	36,331	83,300	55,991	88,815	5.8	115	
1223 to 1264	1½	1.51	1.19	....	....	62.3	....	....	95,809	53,225	85,593	....	43	Dec., 1875.
1265 to 1281	"	1.57	1.16	10.09	12.19	59.4	21.9	....	98.047	54,540	92,871	....	17	Jan., 1876.

Tension tests upon round bars of rolled iron—Continued.

IRON M—Continued.

Test number.	Diameter of bar.	Dimensions of test-pieces.						Stress in pounds at—				Ratio of elastic to tensile limit.	Number of tests in averages.	Date of testing.
		Diameter.		Length.		At fracture.		Elastic limit per square inch.	Tensile limit.					
		Original.	At fracture.	Original.	At fracture.	Reduced area.	Per cent. of elongation.		Observed.	Per square inch original area.	Per square inch fractured area.			
	″	″	″	″	″									
1282 to 1308	1½	1.50	1.16	10.00	12.19	59.1	21.9	35,544	97,095	54,945	93,160	....	27	Feb., 1876.
1309 to 1355	"	1.51	1.15	10.00	12.26	58.8	23.0	35,745	98,364	55,141	92,631	64.0	47	Mar., 1876.
1356 to 1381	"	1.51	1.17	10.00	12.19	60.8	22.9	37,771	98,710	55,131	97,787	61.2	26	May, 1876.
1382 to 1385	"	1.50	1.21	10.00	11.94	64.5	19.4	34,901	98,500	52,736	81,829	66.1	4	May, 1876.
1386 to 1397	"	1.51	1.16	9.50	11.60	59.4	22.0	38,707	102,125	57,052	96,992	67.4	12	Aug., 1876.
Av..	....	....	....	....	....	60.6	21.8	35,733	97,601	54,681	91,409	64.7	176	
1398 to 1403	1⅝	1.63	1.28	9.00	10.93	60.7	21.4	35,850	119,720	57,364	93,036	62.5	5	Aug., 1876.
1404 to 1408	"	1.63	1.26	9.00	11.03	59.8	22.5	35,553	119,880	57,441	93,161	61.0	5	Aug., 1876.
Av..	....	....	....	....	....	60.3	22.0	35,701	119,800	57,402	93,098	61.7	10	

The foregoing record is an abstract from the record of tests of iron received for the manufacture of chain cable at the navy-yard, Washington, the tests having been made by the "Testing Board" appointed for that purpose by the Bureau of Equipment. The test for elastic limit and of the iron in the form of chain links was not adopted by the Board until the winter of 1875–'76, and the records of strength of chain, pages 189 and 192, were obtained subsequently to the receipt of the bolts, and although every care was taken to make the tests in the two forms fairly comparative, there is some little uncertainty as to our success in regard to the lots delivered previous to January, 1876. The iron was delivered from time to time in lots, and each of the above aggregates is a mean of the results of the tests of each lot. Although fairly uniform, it will be noticed that the lots delivered and tested in March and August, 1876, differed greatly in tensile strength from the remainder. The 1⅝″ bars delivered in August (Nos. 1187 to 1221) had among them a large number of bolts which were so brittle that they would not stand bending cold to an angle of 45° without breaking. And of the 1½″ and 1⅝″, of this delivery, a number also failed under this test.

***Tension tests upon round bars of rolled iron*—Continued.**

***Investigation*—Examination of chain iron delivered. *Test-pieces*—Bars as rolled. *Testing-machine*—A.**

IRON M.

Bar.		Dimensions of test-pieces.						Stress in pounds at—			
		Diameter.		Length.		At fracture.		Tensile limit.			Excess in strength over bars rolled true, in pounds.
Test number.	Nominal diameter.	Original.	At fracture.	Original.	At fracture.	Reduced area.	Per cent. of elongation.	Observed.	Per square inch.	Reduced to nominal diameter.	
	"	"	"	"	"						
1409	1⅞	1.90	1.45	10.5	12.69	58.2	20.9	143,200	50,511	....	....
1410	"	1.88	1.47	10.5	12.37	61.1	17.8	139,400	50,216	....	....
Av ..	....	1.89	1.465	......	....	59.6	19.3	141,300	50,363	139,002	2,298
1411	1$\frac{15}{16}$	1.96	1.52	11.5	13.69	60.1	19.0	156,000	51,707	....	....
1412	"	1.96	1.50	11.5	13.87	58.5	20.6	154,600	51,242	....	....
Av ..	....	1.96	1.51	......	....	59.3	19.8	155,300	51,474	151,848	3,452
1413	2	2.01	1.56	12.0	14.56	60.2	21.3	156,000	49,164	....	....
1414	"	2.01	1.55	12.0	14.75	59.5	23.0	167,000	52,820	....	....
Av ..	....	2.01	1.550	......	....	59.8	22.1	161,800	50,992	160,207	1,487
1415	2$\frac{1}{16}$	2.10	1.60	13.0	15.87	58.0	22.0	178,600	51,559	....	....
1416	"	2.10	1.59	13.0	15.75	57.3	21.2	171,200	49,422	....	....
Av ..	....	2.10	1.590	......	....	57.6	21.6	174,900	50,499	168,313	6,587
1417	2⅛	2.15	1.68	13.5	16.50	61.0	22.2	184,600	50,841	....	....
1418	"	2.15	1.65	13.5	16.45	58.8	21.8	186,000	51,225	....	....
Av ..	....	2.15	1.665	......	....	59.9	22.0	185,300	51,033	180,952	4,348
1419	2$\frac{3}{16}$	2.22	1.67	13.5	16.56	56.6	22.6	200,000	51,666	....	....
1420	"	2.22	1.71	13.5	16.75	59.3	24.0	200,000	51,666	....	....
Av ..	....	2.22	1.69	......	....	57.9	23.3	200,000	51,666	193,747	6,253
1421	2¼	2.26	1.78	14.5	18.12	58.6	25.0	205,800	51,296	....	....
1422	"	2.26	1.78	14.5	17.81	57.5	22.8	210,400	51,530	....	....
Av ..	....	2.26	17.8	......	....	58.0	23.9	208,100	51,413	204,418	3,682

No chain links of the above bars (which were purchased for the manufacture of end links, to attach to shackles in chains of less diameter, and for shackles,) were tested. Although the fault of being rolled too full was a good one, as far as strength depended upon it, the errors in the sizes were too great to permit the record to remain uncorrected, in contrast with that of bars of other irons rolled true. The record is an abstract from the books of the navy-yard, Washington, D. C.

SECTION II.

FORM AND PROPORTIONS OF TEST-PIECES.

A PAPER SHOWING BY EXPERIMENT, THE CORRECT FORM AND PROPORTIONS OF TEST-PIECES TO BE USED IN ORDER TO PROCURE CORRECTLY THE TENACITY, ELASTIC LIMIT, ETC., OF VARIOUS METALS—A COMPARISON OF THE STRENGTH OF BARS IN THEIR NORMAL CONDITION WITH THE SAME AFTER REDUCION BY TURNING AWAY THE SURFACE—COMPARING THE RESULTS BY THE TWO TEST ING-MACHINES.

In obtaining the results introduced in the tables of records of bars tested by tension, we have used the two testing-machines A and B.

By the first we have tested all of the bars of diameter greater than one inch, and by the latter, bars in their normal condition of less than one inch diameter, and cylinders turned from the larger bars.

Our tests made upon these cylinders gave results of tensile strength, and elastic limit, which were so much lower than the manufacturers of the various irons considered their products equal to, that some dissatisfaction and doubt as to their correctness were expressed.

Upon examination, we found that in nearly all cases where our results were supposed to be erroneous, on account of a lack of coincidence with results, obtained in some cases by the experiments of private testers of iron, and in others by tests made in government navy-yards, by persons presumed to be competent, the tests whose results cast doubts upon ours had been made upon test-pieces turned from the bars to a reduced diameter, which at one point was reduced by a groove to a much less one, as shown in Fig. 1, page 95.

The errors which arise through the use of this erroneously shaped and proportioned test-piece, have been frequently pointed out, first by Kirkaldy and subsequently by C. B. Richards, member American Society of Civil Engineers; but it does not appear that even as yet the errors which thus arise are fully recognized. As a case in point, the following comparisons of the strength of various-sized bars of iron F, as found by our tests, and as furnished to the manufacturers, by so-called testers, will fully illustrate.

This iron is *always* of so uniform a strength and quality that the test of one bar furnishes most valuable evidence as to the probable strength of another.

Strength per square inch of iron F, as found by, and as furnished to the committee.

Size.	No. of tests.	Strength found.			No. of tests.	Strength furnished.			Difference in averages.
		From—	To—	Average.		From—	To—	Average.	
In.		*Pounds.*	*Pounds.*	*Pounds.*		*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*
2⅝	8	46,164	46,702	46,446	5	58,434	65,357	62,540	16,094
2½	8	47,558	47,871	47,764	4	54,759	60,757	57,236	9,472
2⅜	......	....	....	....	8	50,773	64,099	59,048	....
2¼	8	49,155	49,465	49,623	18	58,111	71,025	63,586	13,963
2⅛	......	....	....	....	15	57,473	64,823	63,300	....
2	9	46,862	49,700	48,182	15	59,440	67,471	63,350	15,218
1⅞	8	48,370	51,300	49,048	12	57,999	66,907	63,230	....
1¾	8	48,792	50,342	50,325	......	....	....	....	....
1⅝	8	49,144	51,300	51,221	12	63,116	75,545	65,083	....
1½	8	49,342	51,840	51,423	......	....	....	....	....
1⅜	8	48,819	50,000	52,396	......	66,312	68,255	67,062	....

With the tabulated statement furnished, the average tensile strength of all sizes combined was given as 63,207 pounds, and the results from the sizes 1¾″ and 1⅝″ had been consolidated; also those from 1½″ and 1⅜″.

With experimenters, developing by accident such a uniformity in the average tensile strength of the various sizes, it is not to be wondered that no attention had been drawn to the variation in strength accompanying variations in diameter, which is plainly indicated in our more correctly made experiments.

The broken test-pieces by which the results were procured were shown to us, and they were of the groove form.

We determined to thoroughly investigate the effect upon the results which were due to variations in the proportions of the test-pieces. The stock of contract chain iron on hand, all of which had been considered to be of a tensile strength of at least 60,000 pounds per square inch (the standard at that time, as it is, or was, also of the British navy), furnished material for experiment, and a number of comparative tests were made by means of grooved test-pieces, and short cylinders, with results as follows:

COMPARISON OF RESULTS OBTAINED FROM CHAIN IRON ON HAND, BY MEANS OF GROOVED TEST-PIECES AND SHORT, TURNED CYLINDERS.

Experiments Nos. 1 *to* 58.

Size.	Dimensions of test-piece.		No. of tests.		Tensile strength per square inch.		Grooves exceed cylinders by—		Appearance of fracture.
	Area.	Length between heads.	Cylinders.	Grooves.	Cylinders.	Grooves.	Pounds.	Per cent.	
In.	*Square inch.*	*In.*			*Pounds.*	*Pounds.*			
1	One-quarter.	1.20	3	3	57,700	71,530	13,830	23.5	Fine steely.
1 1/16	....do	1.20	2	2	56,600	70,600	14,000	24.5	Do.
1 1/8	....do	1.20	3	2	52,600	65,850	13,190	24.0	Do.
1 3/16	....do	1.20	2	2	48,000	59,000	11,000	25.0	Do.
1 1/4	....do	1.20	2	2	58,900	67,400	8,500	14.6	Coarse granulous.
1 5/16	....do	1.20	2	2	52,400	62,800	10,400	20.0	Fibrous.
1 3/8	....do	1.20	2	1	54,200	67,200	13,000	24.0	Do.
1 3/8	....do	1.20	1	......	58,400	67,200	8,800	15.0	Coarse fiber.
1 7/16	....do	1.20	2	2	46,900	54,500	7,600	16.0	Coarse granulous.
1 7/16	....do	1.20	2	2	55,450	65,400	9,950	18.0	Gray fiber.
1 1/2	One-half	1.25	2	2	54,300	66,000	11,700	21.0	Do.
1 9/16	....do	1.25	2	1	58,400	69,700	11,300	19.0	Do.
1 5/8	....do	1.25	2	1	51,500	64,900	13,400	26.0	Coarse granulous.
1 3/4	....do	1.25	2	1	50,900	62,400	11,500	22.0	Do.
1 13/16	....do	1.25	2	1	44,000	53,500	9,500	19.0	Do.
1 7/8	....do	1.25	2	1	48,200	56,900	8,700	18.0	Do.

These results made it evident that the government had *not* received iron of such great tensile strength as was supposed, and this was made more certain by the results procured subsequently by comparative tests upon several of the irons which make up our records. These are here given. One groove-test was made upon each size.

Experiments Nos. 59 *to* 94.

	Iron.		Dimensions of test-piece.		Number of tests.	Ultimate strength per square inch.		Grooves exceed cylinders by—		Remarks.
	Name.	Diameter of bar.	Diameter.	Length.		Groove.	Cylinder.	Pounds.	Per cent.	
		In.	*In.*	*In.*		*Pounds.*	*Pounds.*			
59, 60	C	1 13/16	.864	1.25	2	54,800	47,885	6,915	14.5	Strong and tough.
61, 62	C	1 1/4	.864	1.20	2	57,700	48,600	9,100	10.8	Hard and coarse.
63, 64	C	1 5/8	.564	1.30	2	58,900	56,000	2,900	5.0	Do.
65, 66	C	1 1/2	.564	1.20	2	58,300	52,000	6,300	12.1	Do.
67, 68	C	1 7/16	.564	1.25	2	59,100	45,800	13,300	20.0	Strong and tough.
69, 70	B	1 11/16	.800	1.30	2	67,000	51,900	15,100	29.0	Strong; good stock.
71, 72	B	1 13/16	.800	1.30	2	65,650	53,600	12,050	22.5	Not enough work.
73, 74	J	1 1/4	.800	1.30	2	57,300	50,350	6,950	14.0	Irregular.
75, 76	J	1 5/8	.640	1.40	2	62,200	50,300	11,900	24.0	Do.
77, 78	F	1 1/4	.800	1.20	2	61,900	50,130	11,770	23.5	Soft and ductile.
79, 80	F	1 1/2	.564	1.30	2	60,520	50,400	10,120	20.0	Do.
81, 82	L	1 13/16	.800	1.35	2	75,250	58,390	16,860	29.0	Steel.
83, 84	L	1 1/4	.564	1.37	2	74,400	59,290	15,110	25.0	Do.
85, 86	L	1 1/2	.670	1.35	2	94,400	75,233	19,167	25.0	Do.
87....	L	1 3/8	....	....	1	....	74,600	....	26.5	Do.
88, 89	L	1 7/8	....	....	2	80,000	66,500	13,500	20.0	Do.
90, 91	E	1 1/4	.800	1.30	2	59,520	50,080	9,440	18.0	Tough and strong.
92, 93	E	1 1/2	.564	1.30	2	61,060	50,000	11,060	21.0	Do.

It is to be noticed that the difference between the results obtained by the two methods, is greater in pure refined iron than it is in coarse material. A single experiment made with a test-piece of each form, upon cast iron, confirmed this view; the difference of results was less than 1 per cent., and the cylinder proved that much the stronger.

A series of experiments was undertaken for the express purpose of enabling us to decide upon the correct form and proportions necessary in the test-piece, to insure correct results. The first of this series was made upon eighteen test-pieces turned from a 2″ bar of a remarkably pure refined and uniform iron (K).

No. 1 of this series was 10″ long, and the length decreased upon each successive number until at 18 the groove form was reached. The diameters were nearly constant, except in two cases, where seams encountered made it necessary to turn away more iron. The results are given in the following table:

Experiments Nos. 95 *to* 113.

Number.	Length.		Per cent. of elongation.	Diameter.		Per cent. of contraction area.	Stress when piece began to stretch.		Breaking-stress.		Per cent. of stretch to break.	Remarks.
	Original.	Increased.		Original.	Reduced.		Observed stress.	Stress per sq. inch.	Observed stress.	Stress per sq. inch.		
	Inches.	*In.*		*In.*	*In.*		*Pounds*	*Pounds*	*Pounds*	*Pounds*		
1	10	12.31	23.1	.977	.768	38.2	22,250	29,678	41,150	54,888	54.0	Slight seam.
2	9½	11.81	24.3	.977	.780	36.5	21,000	28,011	41,450	55,288	51.0	
3	9	10.94	21.5	.977	.811	31.1	22,000	29,345	41,500	55,355	53.0	
4	8½	10.37	22.0	.977	.810	31.2	22,000	29,345	41,700	55,622	52.7	
5	7½	9.375	25.0	.977	.757	39.9	23,150	30,840	41,150	54,890	56.2	Do.
6	7	8.81	25.8	.977	.765	38.6	22,800	30,412	41,600	55,488	54.8	
7	6½	7.94	22.1	.975	.755	40.0	21,325	28,562	38,675	51,800	55.1	Bad seam.
8	6	7.34	22.3	.978	.790	34.7	23,000	30,600	41,630	55,418	55.2	
9	5½	6.90	25.4	.976	.760	39.3	22,050	29,475	41,400	55,333	53.3	
10	5	6.06	21.2	.977	.804	32.2	21,950	29,278	41,800	55,887	52.4	Slight seam.
11	4	5.03	25.7	.976	.772	37.4	22,225	29,705	41,550	55,532	53.5	
12	3½	4.44	26.7	.980	.780	36.6	24,000	31,817	41,850	55,482	57.3	
13	3	3.80	27.0	.970	.762	38.3	23,000	31,123	41,425	56,190	55.4	
14	2	2.54	27 0	,472	.377	36.2	5,850	33,428	9,875	56,428	59.0	Seamy.
15	1½	1.90	26.0	.540	.440	34.0	9,675	42,249	13,075	57,096	77.0	Do.
16	1	1.37	37.0	.975	.790	34.3	25,600	34,288	44,000	58,933	58.2	
17	½	.65	30.0	.438	.348	37.0	8,675	57,565	8,950	59,388	97.0	Do.
18	Groove	....	......	.976	.870	20.6	34,000	45,442	53,350	71,300	63.7	

Nos. 13 and 18 of the preceding table are reproduced in the following illustration—

Fig. 1 being No. 18 of the table, and Fig. 2, No. 13.

In Fig. 1, the length, *a b*, was 3″; diameter, *c c*, .976″.

In Fig. 2, the length, *a b*, was 3″; diameter, *c c*, .970″.

The pieces were nearly the same in dimensions, yet the stress at which No. 13 broke, reduced to the square inch, was over 15,000 pounds less than that required to break No. 18. This difference would be very great in estimating the entire strength of the bar from the results of the two pieces. Were those from No. 18 correct, the bar would be equal to a strain of *one hundred* tons, while No. 13 shows that less than *seventy-nine* tons would tear it asunder.

Before proceeding to discuss the tabulation of other results, obtained by other comparative tests, it will be in order to examine the two drawings, and see if the reason for these differing results is not evident, and if it cannot be plainly shown that the cylindrical form is correct, while that of the groove is not so.

Test-cylinders—used in tensional tests.

INCORRECT FORM.

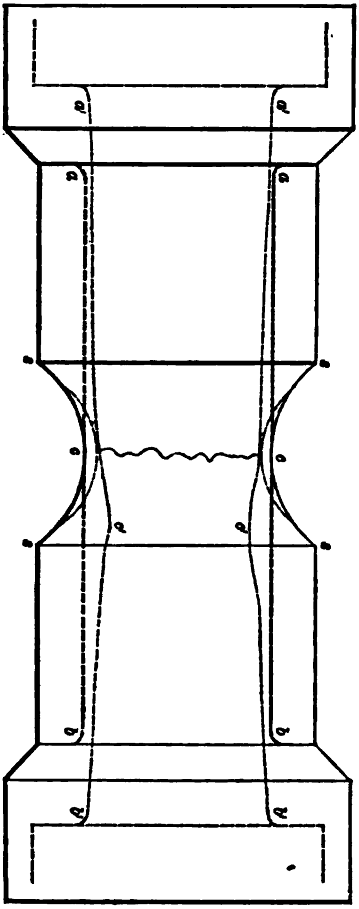


Fig. 1.—No. 18.

CORRECT FORM.

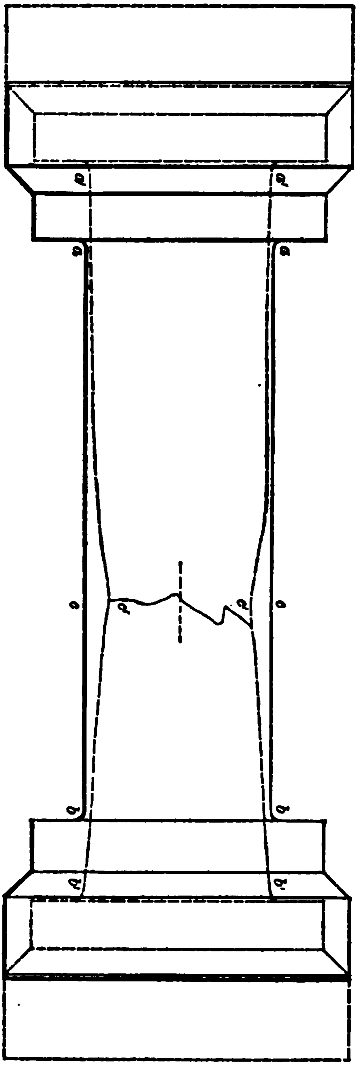


Fig. 2.—No. 13.

[Photographed from iron K. Nos. 18 and 13 of preceding table.]

Beginning with Fig. 1, if the stress at which this specimen was broken, were assumed to be an equivalent to that possessed by a piece of the iron, whose diameter and area were such as the measurements give, viz, diameter, .976 of an inch, with corresponding area at the least section, there exists no reason why a prolongation of this section to a short cylinder should tend to lower its strength.

This prolongation could be produced by simply turning away the shoulders *a s c* and *b s c*, leaving thus a cylinder, as shown by the heavy dotted line *a b*; and if the narrow section received no support from the shoulders, there is no reason that the piece represented by Fig. 1 should possess more strength at this narrow area than that shown in Fig. 2, whose dimensions are nearly the same, less the shoulders; yet practically the first withstood a stress over 14,000 pounds greater than the other. An inspection of the drawings shows the cause. The stress which produces rupture, tends to draw the fibers of the iron adjacent to the point of rupture, together laterally, until just before rupture takes place, the piece consists of two truncated cones, joined at their narrowest sections or apices. This convergence takes place with all metals, but is barely perceptible with those whose texture resembles that of cast iron, is characterized by a long, gradual taper, extending to some distance from the point of rupture in soft, ductile irons, and is abrupt and at times excessive, in material of the nature of low steel.

When the grooved form of test-piece is used, the tendency of that portion of the metal adjacent to the least area to converge is checked by the immediately increasing areas, and thus the stress at which this area yields, is equal in its own strength plus, a portion of that which the cylinder, at its largest area, possesses.

The light dotted lines in Fig. 2 (which have also been reproduced in Fig. 1) represent the appearance of No. 13 of the table after rupture; and a close examination reveals that even with this piece, the length has not been sufficient to permit an interruption to the process of contraction and convergence of the fibers, there being at the point where the tapering line is received by the clamping head of the specimen, evidence that had the cylinder been longer, the point where the lines of taper would have merged into the original parallel lines would have been some distance beyond the junction of the head and the cylinder, the head thus, to a certain extent, acting in the same manner as did the sides of the groove in Fig. 1, and thus increasing slightly the powers of resistance.

By the table we see that this piece (No. 13) did give higher results than those which were longer; the average tensile strength developed by Nos. 2, 3, 4, 6, 9, 10, 11, and 12, being 55,488 pounds per square inch, while No. 13 gives 56,190 pounds, an excess of 751 pounds, thus suggesting that the length of this piece, viz, *three inches*, was not sufficient to insure correct results.

No. 12 gives a result much closer to the averages, as do Nos. 11 and 10.

Assuming that the proper length should be a certain percentage of the diameter, we find No. 13, which is less than four diameters in length, is not long enough; No. 12, of about four diameters, gives correct results.

It was considered that the data obtained by this experiment would possess more value, if we were sure that the differences in results, were in all cases due to differences in length, and not in any, to possible differences in the characteristics of the iron, at the points where the test-pieces were cut from the bars.

It was, of course, impossible to test the *same piece* by both methods and thus obtain certainty; but it was possible to eliminate, to a great extent, errors which might arise from this cause, by the preparation of a set of test-pieces varying in length, but from between each pair of which others should be cut which should be of uniform dimensions.

From a bar $1\frac{1}{16}$ of an inch in diameter, of the same iron, another set of test-pieces was therefore prepared in this manner, nine of nearly uniform proportions, being alternated with nine others, of which the length successively decreased. The pieces were cut from the bars as numbered, No. 2 having been adjacent to No. 1, &c.

In a few cases seams were encountered, which forced us to reduce the diameter below that of pieces in which none occurred.

COMPARISON OF RESULTS OBTAINED BY TEST OF TEST-PIECES OF VARYING PROPORTIONS, ALTERNATED WITH OTHERS OF UNIFORM PROPORTIONS.

[Material, iron K, $1\frac{1}{8}''$.]

Experiments Nos. 114 *to* 132.

Number.	Length.		Per cent. of elongation.	Diameter.		Per cent. of contraction of area.	Stress when piece began to stretch.		Breaking stress.		Per cent. of stretch to break.	Remarks.
	Original.	Increased.		Original.	Reduced.		Observed stress.	Stress per square inch.	Observed stress.	Stress per square inch.		
	Inches.	*Inches.*		*Inches.*	*Inches.*		*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*		
1	5.000	6.522	30.0	.798	.568	49.3	13,400	26,800	26,000	51,989	51.6	Elastic limit, 26,795 pounds per square inch,
2	3.938	5.204	32.0	.798	.564	50.0	14,000	28,000	26,200	52,380	53.5	Elastic limit, 28,194 pounds per square inch.
3	4.500	5.853	30.0	.797	.584	46.3	14,000	28,290	26,190	52,495	53.5	Elastic limit, 28,062 pounds per square inch.
4	3.989	5.084	27.0	.794	.580	46.6	13,900	28,080	26,145	52,807	53.2	Elastic limit, 2[illegible],275 pounds per square inch.
5	3.500	4.605	31.6	.791	.570	48.0	13,000	26,450	26,070	53,032	53.7	Elastic limit, 27,268 pounds per square inch.
6	3.984	5.038	27.0	.789	.575	47.0	13,500	27,613	25,740	53,049	52.5	Elastic limit, 27,820 pounds per square inch.
7	3.000	3.977	33.0	.702	.571	48.0	14,000	28,420	26,100	52,984	53.6	
8	3.987	5.163	31.1	.798	.583	45.3	13,900	28,500	26,200	52,392	53.0	
9	2.472	3.266	32.1	.799	.589	45.6	14,000	27,920	26,500	52,852	53.0	
10	3.864	5.011	29.7	.799	.577	48.0	15,000	20,916	26,300	52,453	57.0	
11	1.989	2.644	32.9	.798	.591	45.0	14,000	28,000	26,590	53,169	53.0	
12	3.756	4.977	32.5	.798	.576	47.8	14,400	28,800	26,220	52,429	55.0	
13	1.500	2.026	35.0	.707	.590	45.2	15,500	31,320	26,275	52,666	59.0	
14	3.999	5.223	30.6	.798	.592	45.0	15,900	31,800	26,300	52,589	60.4	
15	1.000	1.354	35.4	.798	.600	43.5	16,675	33,350	26,590	53,169	63.1	
16	3.995	5.250	31.4	.798	.572	48.6	16,700	33,580	26,030	52,049	64.5	
17	0.500	0.708	41.6	.798	.635	36.6	18,700	37,520	28,665	57,318	65.4	
18	3.980	5.217	31.1	.796	.583	46.4	15,890	31,780	26,220	52,693	60.6	

The first six of the test-pieces were carefully tested for the elastic limit, with the following results:

No. 1. No perceptible change at 26,595 pounds per square inch; at 26,795 pounds elongated .005″, and reduced .004″.

No. 2. No change at 27,994 pounds; at 28,194 pounds elongated .030″, and reduced .002″.

No. 3. At 28,062 pounds elongated .002″, and reduced .003″.

No. 4. At 28,275 pounds elongated .032″, and reduced .002″.

No. 5. At 27,268 pounds elongated .003″, and reduced .001″.

No. 6. At 27,820 pounds elongated .015″, and reduced .003″.

The stress which produced the first perceptible stretch with the above pieces was upon an average of 27,539 pounds, while the average of the elastic limit, by careful test, was 26,058 pounds, thus differing but 1,481 pounds.

Analysis of this table shows that the bar throughout its length was of very uniform strength; the extreme difference between any two of the pieces of uniform length being but 758 pounds per square inch, and the average of the nine (52,395 pounds) being very close to each individual result.

No marked difference, due evidently to the proportions of the test-piece alone, is observable with the pieces which varied in length, until No. 17, which was but one-half inch long, was reached. At this point the difference between it and the uniform pieces on each side of it is about 5,000 pounds per square inch.

Thus we obtained but little additional information as to the tensile strength, but in the matter of elastic limit we gain points of interest. We find that in the two ends of the bar there was in this respect considerable difference. Nos. 2, 4, 6, 8, 10, and 12, all pieces of uniform length, gave an elastic limit of 28,485 pounds per square inch, none varying greatly, such variations as existed indicating that the end from which No. 1 was cut had a lower limit than the other, No. 2 developing 28,000 pounds, and No. 12, 28,800, the increase, however, on the intermediate numbers being irregular. Nos. 14, 16, and 18, however, ranged from 31,800 to 33,580, averaging 32,353 pounds.

The first six pieces which varied in length, viz, Nos. 1, 3, 5, 7, 9, and 11, gave an elastic limit of 27,980 pounds, differing thus but a little from that developed by the uniform pieces.

At No. 13, as at 14, a rise in the elastic limit was noticeable, but in only one case (No. 17) was the variation sufficient to indicate that the shortness of the specimen had an influence. The ratios between the elastic limit and the ultimate strength increased both with the uniform test-pieces and those varying in length, and thus the results indicate that at that portion of the bar there was a slight change in its character.

It was considered that it was possible that the bar having been rolled in midwinter, in a cold climate, the difference of the temperature which probably existed between that at the end of the bar farthest from the rolls and the one nearest to them, and in which the two ends were cooled at different degrees of rapidity, might have affected an iron so fine in its nature. Subsequent experiments, however, on iron which it was known had been so exposed failed to detect any marked difference between the two ends of the bars that could be surely attributed to this cause.

This experiment was as follows: At the time of rolling the bars of iron F, second lot, the temperature in the open air was below 30°; the bars were rolled about 40 feet long; the ends which passed first into the rolls were, while the bars were cooling, about 3 feet from a raised door, and the temperature of this point was about 31°; the inner ends of the bar were cooled in a temperature of 60° or 65°. It was thought possible that the difference in temperature in which the two ends cooled *might* produce some effect, hence a piece from each end of each bar was tested, three tests upon each piece. The record is given in detail in the record of bars; here it is but necessary to give the results, which so far as this question is concerned decided nothing positively.

Elastic limit and tensile strength of the two ends of bars of iron F cooled in temperatures of 30° to 65° Fahrenheit, respectively.

Size.	Elastic limit per square inch.		Excess.		Tensile strength per square inch.		Excess.		Reduced area.		Elongation.	
	Warm end.	Cold end.	Warm over cold.	Cold over warm.	Warm end.	Cold end.	Warm over cold.	Cold over warm.	Warm over cold.	Cold over warm.	Warm over cold.	Cold over warm.
In.	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Pr. ct.*	*Pr. ct.*	*Pr. ct.*	*Pr. ct.*
1	41, 333	36, 033	5, 300	....	51, 232	51, 259	....	397	4. 0	......	1. 0	......
1⅛	32, 978	32, 224	754	....	50, 456	50, 178	278	......	1. 7	......	......	5. 2
1¼	37, 069	31, 860	5, 209	....	49, 846	50, 328	....	482	......	0. 7	......	0. 5
1⅜	35, 951	38, 559	....	2, 608	49, 762	49, 126	636	......	0. 5	......	3. 1	......
1½	35, 066	33, 552	1, 514	....	49, 342	49, 915	....	573	4. 5	......	......	2. 3
1⅝	36, 754	31, 914	4, 840	....	49, 644	49, 740	....	96	......	1. 6	1. 5	......
1¾	35, 000	34, 741	319	....	49, 339	49, 628	....	289	0. 7	......	0. 4	......
1⅞	....	....	....	....	48, 550	48, 958	....	408	......	......	......	......
2	31, 184	33, 161	....	1, 977	48, 459	47, 048	1, 411	......	2. 3	......	0. 5	......

If the results obtained indicate more than accidental variations, it is that the *limit of elasticity* was *higher* in the end slowly cooled, and that the tensile strength was somewhat lower.

The reduced area and per cent. of elongation are compared at the *tensile limit*, the pieces having been finally broken by different methods.

So far as their evidence can be considered valuable, it indicates that the end which was slowly cooled was generally more *ductile* than the end which cooled rapidly.

If on future experiments results are found which confirm those obtained by this set, they will have a new value; as it is, they are not to be perfectly depended upon as deciding anything.

The experiments up to this point having established to our satisfaction that in order to procure correct results it was requisite that a test-piece should be not less than four times its diameter in length, the question now arose whether variations in this basis, the diameter, would produce important differences in results. To solve this, two sets of test-pieces were prepared from a bar of 1⅞″ iron K, in this manner:

One set consisted of seven pieces, the first one of which was 4″ in length and 1″ in diameter; each successive piece was reduced to a diameter less than that of its predecessor by .1″, and the length cut equal to four times the diameter, No. 7 thus being of .4″ diameter and nearly 1″.6 in length.

The other set consisted also of seven pieces, of which No. 1 was of the same dimensions as No. 1 of the first set; the remainder of the pieces were made successively decreasing in diameter as in the first case, but the length remained the same throughout, viz, 4″, except in case of No. 7, which was, through accident, a trifle shorter. The two sets were cut from the bar in the following order: No. 1 of first set, No. 1 of second, No. 2 of first, No. 2 of second, &c.; thus the same number in both tables indicates adjacent portions of the bar.

The results of the tests are given in the following tables:

Experiments No. 133 *to* 147.

MATERIAL, IRON K; DIAMETER OF BAR, 1⅛″.

FIRST SET.

[Test of seven pieces, successively decreasing in length and diameter, each piece being (approximately) four diameters long.]

Number.	Length in inches.		Per cent. of elongation.	Diameter in inches.		Per cent. of contraction of area.	Stress when piece began to stretch.		Ultimate stress.		Per cent. of stretch to break.
	Original.	Increased.		Original.	Reduced.		Observed stress.	Stress per square inch.	Observed.	Per square inch.	
							Pounds.	*Pounds.*	*Pounds.*	*Pounds.*	
1	3.98	5.07	27.4	1.004	.770	41.2	21,850	27,078	42,475	53,688	51.5
2	3.54	4.54	28.0	.900	.694	40.5	19,000	29,869	35,000	55,023	54.3
3	3.20	4.15	30.0	.800	.625	38.9	15,152	30,143	27,350	54,800	55.4
4	2.77	3.54	28.0	.710	.554	39.1	12,000	30,310	22,225	56,138	54.0
5	2.38	3.04	27.8	.601	.470	38.8	9,250	32,616	15,725	55,448	58.8
6	1.95	2.52	30.0	.501	.388	40.0	7,225	36,656	11,000	55,809	65.7
7	1.56	1.92	23.0	.400	.301	43.0	*6,575	*52,348	7,475	59,514	68.0

* Probably an error.

SECOND SET.

(2) [Test-pieces constant in length (4″), diameter diminishing by $\frac{1}{10}$″, test-pieces from same bar.]

1	3.98	5.17	30.0	1.004	.760	42.7	22,999	29,051	42,825	53,461	54.4
2	3.98	5.06	27.1	.901	.707	38.6	20,250	31,765	35,000	54,902	58.0
3	3.98	5.05	27.0	.800	.600	43.7	14,552	28,049	27,175	54,067	58.5
4	3.98	4.97	25.0	.705	.544	40.5	11,650	29,849	21,225	54,881	55.0
5	3.97	5.00	26.0	.601	.458	41.9	9,600	33,851	15,625	55,095	61.4
6	3.95	5.00	26.6	.500	.381	42.0	6,100	31,075	10,725	54,636	56.8
7	3.65	4.47	22.5	.403	.295	46.4	4,400	34,509	6,775	53,187	65.0

A specimen from the same bar was also carefully tested for the elastic limit, which was found to be at 28,664 pounds per square inch, at which stress it had permanently elongated from 3″.649 to 3″.575, and had reduced in diameter from .977″ to .675″, the elongation before the relaxation of the stress being .003″ and the reduction of diameter .002″ greater.

Analysis of the results in the first set shows that as the dimensions of the test-piece decreased, there was a constant increase in the elastic limit and an irregular increase of the tensile strength, which must have been due either to the decreasing length, decreasing diameter, or to changes in the character of the material.

The second set of test-pieces, through some inexplicable cause, proved very irregular, in comparison with the others cut from the same bar, so much so that their record is of no great value in an investigation where so much deduction depends upon very slight facts. The largest and smallest pieces were more alike in their tensile strength than were any of the intermediate sizes.

The elastic limit rose irregularly as the diameter decreased, showing a gain of about 5,000 pounds between the extremes.

It was thought advisable to search further and see if this would always prove the case. Four other test-pieces were prepared from a 2″ bar of iron P, two of which were made as large as we could break with safety, and the others as small as could be trusted for accurate results. They were tested with results which did not confirm the action of the previous set as regards the elastic limit, as with these the larger pieces developed slightly higher elastic limit than the small ones, but fully confirmed the results as to the smaller test-piece indicating the greater tensile strength.

Experiments Nos. 148 *to* 152.

MATERIAL, IRON P; DIAMETER OF BAR 2″.

[Test-pieces of different diameters and of length equal to six diameters.]

Number.	Diameter.			Length.			First stretch.		Contraction of area.		Per cent of elongation.		Ultimate stress.	
	Original.	Tensile limit.	Fracture.	Original.	Tensile limit.	Fracture.	Observed.	Per square inch.	Tensile limit.	Fracture.	Tensile limit.	Fracture.	Tensile limit area.	Original area.
	In.	*In.*	*In.*	*In.*	*In.*	*In.*	*Lbs.*	*Lbs.*	*Pr. ct.*	*Pr. ct.*			*Lbs.*	*Lbs.*
1	1.238	1.063	.681	7.4	9.37	9.86	37,425	31,000	26	60	25½	20	67,460	49,542
2	1.245	1.068	.787	7.4	9.37	9.89	38,300	31,700	26½	59½	23	20	67,630	49,404
3	.505	.425	.327	2.99	3.61	3.81	5,000	30,575	28	57½	21	28½	69,000	49.924
4	.498	.421	.328	2.99	3.84	4.02	6,500	28,788	28½	57	28	33	69,300	49,820

The difference in results obtained is not so great as to be of value, were it not that what little there is, confirms the views already expressed that in obtaining the tensile strength, we are liable to rate that of a large bar at too high a figure if we depend upon the results obtained from a test-piece which represents the character of the *core* and not that of the entire bar, the iron being strongest at the centre.

The difference in tensile strength is more marked at the "tensile limit" than at fracture, at which point the smaller test-piece not only showed greater strength, but also greater elongation and reduction of area.

All of the tests in this investigation having been made upon iron with considerable tensile strength, it was thought advisable to make one more experiment with a bar of very soft and ductile iron.

A 2″ bar was selected, which, although of low tensile strength, was very tough and ductile.

From this nine test-pieces were turned of lengths from 8″ down to the groove form, each successive piece being nearly 1″ shorter than its predecessor, and all being of nearly uniform diameter. They were tested with the following results:

Experiments Nos. 153 *to* 162.

[To determine necessary proportions with very soft iron (D).]

Number.	Diameter.			Reduction of area.		Length.			Per cent. elongation.		First stretch per square inch.	Ultimate stress per square inch.			Per cent. of stretch to break.
	Original.	Tensile limit.	Fractured.	Tensile limit.	Fractured.	Original.	Tensile limit.	Fractured.	Tensile limit.	Fractured.		Original.	Tensile limit.	Fractured area.	
	In.	*In.*	*In.*	*Pr. ct.*	*Pr. ct.*	*In.*	*In.*	*In.*			*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	
1	1.000	.....	.693	......	52.0	8.00	9.63	10.25	20.3	28.0	28,619	45,800	......	95,373	62.5
2	.999	.853	.675	27.0	54.8	7.00	8.82	9.09	26.0	29.8	30,000	45,930	62,992	100,614	62.1
3	1.000	.880	.704	22.5	50.3	5.82	7.18	7.57	23.2	29.9	26,700	45,995	59,396	92,818	58,2
4	.909	.881	.700	22.2	50.9	4.90	6.04	6.42	23.8	31.0	28,060	45,768	58,850	93,230	59.4
5	.908	.881	.684	......	53.1	3 95	5.02	5.33	27.3	35.0	26,588	40,561	59,740	99,413	57.1
6	1.000	.853	.705	22.3	50.3	2.98	3.70	4.05	24.3	36.1	....	46,759	60,244	94,070	...
7	1.001	.863	.700	25.6	51.0	1.98	2.41	2.78	21.9	40.4	28,000	46,734	62,874	95,569	60.0
8	1.000	.849	.718	28 0	48.4	.975	1.25	1.42	22.0	45.2	28,200	47.033	66,813	93,455	58.4
9	.985	.....	.897	......	17,0	Groove	......	......	......	......	48,000	61,023	....	73,587	78.7

The results indicate that with iron of this character a length equal to four diameters is not quite sufficient to insure accurate results.

No. 5, which was nearly four diameters in length, gave a tensile strength greater by 689 pounds per square inch than was developed by Nos. 1, 2, 3, and 4, which were very uniform, No. 4 being five diameters in length and *long enough.* No. 6, of three diameters, gave still higher results, which were not subsequently increased as the length lessened until the groove form was reached, when there was a sudden rise of over 13,000 pounds, a difference equal to 33 per cent. of the actual strength.

Finally, our results lead us to the conclusion, that in testing iron, no test-piece should be of less than ½″ diameter, as inaccuracy is more probable with a small than with a large piece, and the errors are more increased by reduction to the square inch; that the length should not be less than four times the diameter in any case, and that with soft, ductile metal five or six diameters would be preferable.

These rules hold good in testing steel also, as may be seen by the appended results, which have been submitted by the committee, of tests made upon Bessemer steel, which results are confirmed by those obtained by Colonel Wilmot at the Woolwich Arsenal, made also upon Bessemer steel, which we quote, as follows:

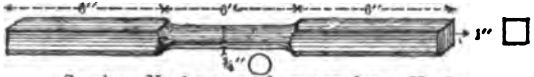
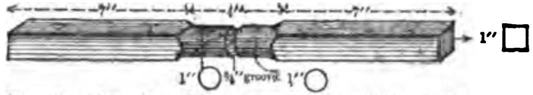
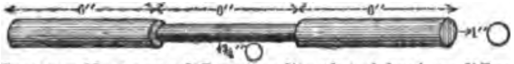
Material, Bessemer steel; test-pieces of one square inch area.

		Pounds per square inch.
By groove form:	Highest tensile strength	162,974
	Lowest tensile strength	136,490
	Average tensile strength	153,677
By cylinder:	Highest tensile strength	123,165
	Lowest tensile strength	103,255
	Average tensile strength	114,460

The grooved thus exceeding the cylinder form 32 to 34 per cent.

THE EDGAR THOMPSON STEEL WORKS (LIMITED).

Statement of tests of Bessemer rail bar steel, made on a Riehlé testing-machine, by P. F. Brendinger, engineer, Point Bridge, Pittsburgh, Pa., February 25, 1876.

Test.	Description of specimens.	Original cross-section.		Fractured cross-section.		Breaking strength.	Ultimate tensile strength per square inch.		
		Size.	Area.	Size.	Area.		Original area.	Fractured area.	
No. 1	Length 18″ out to out —1″ □ bar, turned cylindrical for 6″ in center, 6″ collar at each end.	$\frac{3}{4}$″ ○	.4417 □″	$\frac{19}{32}$″ ○	.2770 □″	49,000	$\frac{49,000}{.4417}=110,936$	$\frac{49,000}{.2770}=176,895$	 Specimen No. 1 was cut from same bar as No. 2.
No. 2	Length 18″ out to out —1″ □ bar, turned cylindrical for 4″ in center, leaving 7″ collar at each end. Groove in center.	$\frac{3}{4}$″ ○	.4417 □″	$\frac{23}{32}$″ ○	.4057 □″	66,000	$\frac{66,000}{.4417}=149,422$	$\frac{66,000}{.4057}=162,681$	 In center of specimen No. 2 a groove ¾″ ○ x ¾″ long was turned.
No. 3	Length 18″ out to out, cylindrical specimen 1″ ○, turned to ¾″ ○ for 6″ long in center.	$\frac{3}{4}$″ ○	.4417 □″	$\frac{5}{8}$″ ○	.3068 □″	42,000	$\frac{42,000}{.4417}=95,087$	$\frac{42,000}{.3068}=136,897$	 Specimen No. 3 was a different quality of steel, having a different proportion of carbon from specimens Nos. 1 and 2.

SECTION III.

COMPARATIVE STRENGTH OF BARS IN THEIR NORMAL CONDITION AND AS REDUCED BY TURNING AWAY THE SKIN AND ADJACENT IRON.

A few tests were made by tension for the double purpose of ascertaining if the strength per square inch of iron bars, with or without the skin, would prove the same, and to compare the results obtained by the two testing-machines A and B.

The first series was made upon a number of bars of our most uniform iron, one which had received very thorough work. The detailed history of these tests is given in the "Record of bars," from which an abstract will be here inserted, which will show simply their relative strength as tested by test-pieces which were reduced to various extents, and by others which were not so reduced.

Comparison of strength of bars tested by tension in their normal condition, as slightly reduced, and as reduced to cylinders.

IRON F.

Size of bar.	SECOND LOT.			THIRD LOT.		
	Strength per square inch.			Strength per square inch.		
	Bars not reduced.	Bars reduced slightly.	Bars reduced to cylinders.	Bars not reduced.	Bars reduced slightly.	Bars reduced to cylinders.
In.	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*
1	52, 819	52, 810	51, 380	51, 921	....	51, 128
1⅛	52, 267	51, 675	50, 317	50, 149	....	50, 530
1¼	52, 620	51, 949	50, 087	52, 729	....	49, 801
1⅜	52, 537	50, 403	49, 444	52, 839	....	48, 819
1½	51, 456	50, 799	49, 628	50, 820	....	51, 838
1⅝	50, 970	49, 605	49, 642	50, 529	....	49, 144
1¾	49, 738	50, 201	49, 483	50, 457	....	48, 702
1⅞	49, 061	49, 682	48, 754	49, 744	....	49, 370
2	47, 569	48, 170	47, 774	47, 872	....	48, 280
2¼	....	....	....	48, 505	49, 164	49, 290
2½	....	....	....	47, 344	48, 475	47, 428
2¾	....	....	....	....	....	46, 446
3	....	....	....	....	....	47, 761
3¼	....	....	....	....	....	47, 014
3½	....	....	....	....	....	47, 000
3¾	....	....	....	....	....	46, 667
4	....	....	....	....	....	46, 322

Which results, being grouped, show that in the second lot, in which there were nine comparative tests—

The rough bar exceeded the turned in strength in seven cases.

The rough bar exceeded the cylinder in strength in eight cases.

The turned bar exceeded the rough in strength in two cases.

The turned bar exceeded the cylinder in strength in eight cases.

By the eleven comparative tests of rough bars with cylinders of the third lot—

The rough exceeded the cylinder in six cases.

The turned bar exceeded the rough in two cases.

It will be noticed that the preponderance of the cases where the strength of the reduced bars exceeded that of the rough ones, occurred with the bars of great diameter, that with one exception, the strength of the bars of less than 2″ diameter, as shown by the test of the cylinder, was *less* than that shown by test of entire bars, and that in case of the

2″, 2¼″, and 2½″ the reverse was the case. This may indicate that the core of these larger bars was less heated in the furnace than the rest of the bar, hence retained more strength.

A number of tests in the same connection were made upon bars of other irons, with results as follows:

Consolidation of results from 226 tests by tension upon test-pieces, with and without skin, showing preponderance of strength in favor of the bar in normal condition.

TESTING-MACHINE A.

Iron.	Size of bar.	Number of tests. Rough.	Number of tests. Turned.	Tensile strength per square inch. Rough.	Tensile strength per square inch. Turned.	Excess of strength. Rough over turned.	Excess of strength. Turned over rough.
	In.			*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*
D	1¾	1	1	51, 238	49, 419	1, 814	......
D	1⅝	1	1	51, 127	50, 383	744	......
D	1⅞	1	1	52, 156	53, 347	......	1, 191
D	1¼	1	1	51, 275	51, 271	4	......
C	2	1	1	49, 678	49, 735	33	......
C	1⅞	1	1	49, 095	48, 726	369	......
E	1 13/16	1	1	51, 499	51, 895	......	396
C	1⅞	1	1	51, 730	49, 044	2, 695	......
E	1¾	1	1	51, 606	51, 740	......	134
E	1⅝	1	1	51, 944	50, 844	1, 100	......
E	1⅝	1	1	55, 415	55, 409	6	......
E	1⅝	1	1	52, 255	51, 843	412	......
E	1¼	1	1	53, 894	53, 309	585	......
E	1⅝	1	1	53, 098	53, 497	......	399
Hammered	1⅝	1	1	52, 570	52, 424	146	......
Hammered	1⅝	1	1	56, 818	54, 143	2, 675	......
Hammered	1¼	2	2	57, 280	55, 021	2, 259	......
Hammered	1⅜	1	1	55, 542	55, 805	......	263
		20	20				

UPON IRON F, ALREADY TABULATED.

Iron.	Size of bar.	Number of tests. Rough.	Number of tests. Turned.	Tensile strength per square inch. Rough.	Tensile strength per square inch. Turned.	Excess of strength. Rough over turned.	Excess of strength. Turned over rough.
	1	5	1	52, 819	52, 810	9	......
	1⅛	5	1	52, 267	51, 675	592	......
	1¼	5	1	52, 620	51, 949	671	......
	1⅜	5	1	52, 537	50, 403	2, 134	......
	1½	5	1	51, 456	50, 799	657	......
	1⅝	5	1	50, 970	49, 605	1, 365	......
	1¾	5	1	49, 738	50, 201	....	463
	1⅞	5	1	49, 061	49, 682	....	621
	2	5	1	47, 569	48, 170	....	601
	2¼	2	2	48, 505	49, 164	....	659
	2½	2	2	47, 314	48, 475	....	1, 131
		49	18				

TESTING-MACHINE B.

Iron.	Size of bar.	Number of tests. Rough.	Number of tests. Turned.	Tensile strength per square inch. Rough.	Tensile strength per square inch. Turned.	Excess of strength. Rough over turned.	Excess of strength. Turned over rough.
C	1⅛	4	3	52, 949	52, 796	153	......
C	1	3	3	54, 076	53, 103	973	......
C	¾	6	5	55, 725	55, 311	414	......
C	⅝	5	6	58, 496	62, 813	....	4, 317
D	1	6	4	53, 600	52, 428	1, 172	......
K	1	3	3	62, 269	60, 536	1, 733	......
K	1	4	3	61, 945	62, 156	....	211
Contract iron	¾	3	4	60, 466	59, 696	770	......
F, first lot	1	4	4	52, 155	51, 547	608	......
F, first lot	1	3	3	52, 645	51, 540	1, 105	......
F, first lot	⅝	6	5	57, 257	57, 668	....	411
F, first lot	⅝	6	5	55, 644	54, 964	680	......
F, third lot	¾	3	1	50, 716	50, 374	342	......
	¾	3	1	51, 969	50, 276	693	......
	⅝	3	1	52, 032	51, 431	601	......
	⅝	3	1	53, 755	52, 775	980	......
	¾	3	1	....	....	....	......
		71	53				

In case of the ½″ bars of iron C, of which the turned so greatly exceeded the rough in strength, there is some reason to suspect that a piece of the bar of iron K was, by mistake, substituted for that of C. In the case of iron K, where the turned exceeded the rough bar, the threads of the latter stripped.

The evidence accumulated indicates that the strength of the skin of the bar is greater in proportion to its area than that of the rest of the bar.

In making the foregoing tests, we find that in sixteen comparative tests of small bars by testing-machine B, and in thirty comparative tests upon larger bars by testing-machine A, making forty-six in all, in thirteen cases of the former and twenty of the latter, thirty-three, or over 72 per cent. of the excess of strength, occurred with bars in their normal condition.

With iron F, which was so uniform in its structure that any peculiarity which manifested itself by any particular test seemed to indicate a possible law, we find that, with the bars which received the most work, viz, from 1″ to 1⅝″, inclusive, the rough bars were stronger than the turned; above 1⅝″ the more slightly worked sizes reversed the proportion. If this result can be accepted as indicative, it would be wise in estimating the entire strength of a large bar by the data afforded by the test of a cylinder turned from its center to, as has already been said, consider it probable that an overestimate would be made; for instance, the strength of the 2¼″ bar was by actual test 192,861 pounds of the entire bar, by test of turned bar 195,481 pounds, by test of cylinder 195,981 pounds, showing a possible overestimate of 3,120 pounds by use of a cylinder turned from the core.

SECTION IV.

ELEVATION OF THE LIMIT OF STRESS.

A PAPER DESCRIBING A SERIES OF EXPERIMENTS TO DETERMINE FACTS IN REGARD TO THE OPERATION OF THE LAW CALLED THE ELEVATION OF THE LIMIT OF STRESS.

The discovery that wrought iron, after having been subjected to a steady stress up to the point of its ultimate strength, would, if then released from stress and permitted to rest, experience an elevation in both its elastic and tensile limit, was made by Prof. Robert H. Thurston in November, 1873, and by the chairmen of these committees a short time afterward while carrying on an investigation by tension, Professor Thurston having made his discovery by torsion tests; the discoveries were entirely independent, neither experimenter having any knowledge of the other's work.

As at the beginning of the series of tests incorporated in this report, but little data had been obtained as to the operation of this new law, it was thought worth while to, while making investigations in regard to chain iron, utilize at slight expense many of the test-pieces, in investigating its action. By bringing a test-piece to the tensile limit all data as to its strength is obtained; and by carrying the test to rupture, we gain simply the dimensions after rupture, and means to reduce the strength, &c., to those measurements.

We therefore released a number of test-pieces from stress when the tensile limit was reached, and, preserving them for various periods, eventually broke them, with results as given in the following paper, from which the following abstracts bearing upon this phenomena are taken, and in addition the results of a few experiments, which are not incorporated in the records of bar tests, attention having been paid only to the elevation of strength.

It seems proper that the record of the first experiment, during which this phenomena was ever noticed as taking place upon iron subjected to *tension*, should be given here, although, except that it records the discovery of the law, the data has but little value when compared with some of the later more carefully made experiments.

Prof. Spencer F. Baird, to whom the experimenter furnished a copy of the record, considered the discovery of importance, as did Professor Henry, and the former sent it to the Journal of the Franklin Institute, which issued it in the following editorial in its issue of March, 1874.

[Editorial.]

INCREASE OF RESISTING POWER OF METALS UNDER STRESS.

In our issue of December last, p. 374, we announced the discovery, made a few weeks earlier—at the time of the meeting of the National Academy of Science at the Stevens Institute of Technology—by Prof. R. H. Thurston, of a gain in power of resistance in metals left under stress during periods varying from one to several days.

The formal announcement of this remarkable and important phenomenon was made to the American Society of Civil Engineers in November, and appeared simultaneously in the transactions of that society and in this journal.

We have lately received, through the kindness of Professor Baird, a memorandum relating to experiments made January 27 and 28, 1874, by Commander Beardslee, which exhibit a similar action.

The experiment of Professor Thurston were made with his "autographic testing-machine"* upon a variety of metals; those now presented were made by the ordinary form of tensile lever machine.

This memorandum is as follows:

Test of Bloom iron, turned to the diameter $_{16}$*ths (nearly)* = $\frac{1}{4}$ *square inch section. January,* 1874.

"Lever ceased to rise at 24,300 pounds. It was then balanced by deducting 1,225 pounds, and left, with a balancing strain of 23,075 pounds, from 2 p. m., January 27, till 7 a. m., January 28, *when it was found that the lever had raised*, and it took 125 pounds to rebalance it.

"The strain was then put on gently, and *the lever continued to rise until it reached* 28,250 *pounds, when it ceased to rise and sank.* We balanced the lever at this point by deducting 2,150 pounds strain.

"Limit of E., 27th, 24,300; balanced at 23,075 pounds.

"Limit of E., 28th, 28,250; balanced at 26,100 pounds."

In Professor Thurston's note to the American Society of Civil Engineers, he states the increase of resisting power noted at a maximum of 25 per cent. in twenty-four hours.

The increase observed in the specimens just referred to is 100 (26,100—23,075) ÷ 23,075 = 13.1 per cent, in seventeen hours.

The interest and importance attaching to the discovery of these facts to the engineering profession, as well as to science, make it eminently desirable that still further researches should be made on the effect of prolonged stress, compression as well as tensional, and with every variety of material.

We would call particular attention to the fact that the action here noted is not merely a negative one, as observed by the original discoverer, but is apparently not only an increase of power of resistance, but an actual, positive increased molecular effort, as is shown by the rise of the lever during the period of rest in Commander Beardslee's experiment.

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*Journal of the Franklin Institute. April, 1873.

The same editorial makes reference to the discovery of the law by Professor Thurston, as follows:

A NOTE ON THE RESISTANCE OF MATERIALS.—BY PROF. ROBERT H. THURSTON.—The following is the text of the communication of Professor Thurston to the American Society of Civil Engineers, on the subject of certain unexpected results manifested by metals under strain, to which reference was made in the Journal (Vol. lxvi, p. 374). For the copy we are indebted to the author.

"On the 13th ultimo, an apparatus for determining the torsional resistance of materials, which I had designed for use in illustration of my course of instruction, and to which I had fitted an automatic recording attachment, was exhibited to the National Academy of Science, at the late session held at this place, for the purpose of showing the peculiar adaptability of the machine for the determination and analysis of the action of physical and molecular forces in resisting stress, and to illustrate the bearing of experiments already made upon scientific investigations of molecular relation.

"At the close of the meeting, a test piece of wrought-iron was left in the machine, exposed to a strain which had passed the limit of elasticity, and with a distortion of 45 degrees, the intention being to determine whether, as has been suspected by some writers and by many engineers, 'viscosity' is a property of solids; whether a flow of 'solids'* could occur under long-continued strain just equilibrating, when first applied the resisting power of the material, or whether the 'polarity' of Professor Henry is an absolutely unrelaxing force.

"The metal was left under strain twenty-four hours, and had not then yielded in the slightest degree. This result and the results of other similar experiments since made confirming it, indicate that metal strained far beyond the limit of elasticity, as above described, does not lose its power of resisting unintermitted static stress.

"The important bearing of this fact upon the availability of iron, and of steel, which also behaves similarly, for use in constructions exposed to severe strains, is readily seen.

"After noting the result obtained as stated, it was attempted to still further distort the test-piece, when the unexpected discovery was made that its resisting power was greater than when left the previous day, an increase resistance being recorded amounting to about 25 per cent. of the maximum register the preceding day, and approximating closely to the ultimate resistance of the material. Repeated experiments continued up to the date of writing confirm the following previously undemonstrated principle: That iron and steel, if strained beyond the limit of elasticity, and left under the action of the distorting force which has been found just capable of equilibrating their power of resistance, gain resisting power to a degree which has a limit in amount approximating closely, if not coinciding with, the ultimate resistance of the material, and which has a limit as to time in experiments hitherto made, of three or four days.

"Releasing the piece entirely and again submitting it to the same force immediately does not produce this strengthening action.

"There is some evidence, that is confirmed by theoretical dynamic principles, that the increase of strength noted is not accompanied by a change of resilience, but that the gain of resisting power is at the expense of a proportional amount of ductility.

"The diagrams obtained during this research will be presented at a future time, when the investigation shall have been completed.

"The interest and importance attaching to the discovering of the principles above enunciated, to our profession, as well as to science, will, I hope, justify the presentation of this note."

It will be noticed that the results of the experiments to be given confirm the views of Professor Thurston as to the decrease of ductility of the material, but some of them indicate that although the increase of resistance may not begin "immediately," yet that a very trifling interval of time elapses before it can be noticed.

The foregoing papers have been reproduced here, because they give about all that was known on this subject at the date when these experiments were begun.

It is proper that it should be stated that as on no future occasion was the lever found to have raised during the period of rest, the assertion that it so acted, during the original test, was in all probability based on some error.

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*Mon. H. Tresca; Sur l'Ecoulement des Corps Solides. Paris, 1869-'72.

During a few of the earlier experiments no exact record of the period of rest was preserved.

The following test-pieces were upon one day strained to the tensile limit, and at some time during the next day broken, with the results as follows:

No. 1. Contract chain, 2″ bar; gain per square inch by rest, 3,337 pounds =6.6 per cent.

No. 2. Contract chain, 1⅞″ bar; gain per square inch by rest, 2,238 pounds=4.4 per cent.

No. 3. Contract chain, 1¼″ bar; gain per square inch by rest, 7,506 pounds=15.1 per cent.

No. 4. Contract chain, 1⅛″ bar; gain per square inch by rest, 8,560 pounds=17.0 per cent.

No. 5. Iron D, 2″ bar; gain per square inch by rest, 6,931 pounds= 14.8 per cent. (bar test No. 430).

No. 6. Iron D, 1⅞″ bar; gain per square inch by rest, 7,395 pounds= 15.8 per cent. (bar test No. 432).

No. 7. Iron D, 1¾″ bar; gain per square inch by rest, 7,873 pounds= 16.7 per cent. (bar test No. 434).

No. 8. Iron D, 1⅝″ bar; gain per square inch by rest, 8,606 pounds= 16.7 per cent. (bar test No. 436).

No. 9. Iron D, 1½″ bar; gain per square inch by rest, 6,881 pounds= 14.0 per cent. (bar test No. 438).

No. 10. Iron D, 1¼″ bar; gain per square inch by rest, 8,306 pounds= 16.5 per cent. (bar test No. 440).

No. 11. Iron K, 1¼″; gain per square inch, 4,203 pounds=8.2 per cent.

No. 12. Iron K, 1″; gain per square inch, 5,040 pounds=8.8 per cent.

Nos. 1 and 2 were of ordinary coarse chain iron, No. 5 of a remarkably brittle bar of iron D, of which photograph is given in this report (Plate X).

Nos. 11 and 12 were of a fine, strong iron, with considerable carbon, breaking with a steel-like fracture; the remainder were all from tough, fibrous iron. The indications were that the latter type of iron gained the most by the rest. While testing the foregoing pieces, the stress which produced the first perceptible elongation (about .002″) was observed, and on the first test this stress was from 61 to 70, averaging about 65 per cent. of the ultimate strength. Upon testing them the second time the stress which produced first stretch was nearly identical with the ultimate strength.

At the instant that the specimen ceased to resist an increase of strain, the reduction of area, and elongation were measured, and the amount of changes of form which had then taken place bore the following ratios to the entire change, produced by tension carried to rupture, viz: In reduction of area, 51 to 70, averaging 59 per cent.; in percentage of elongation, 73 to 88, averaging 79 per cent.

The foregoing tests were, with the exception of those made upon iron D, not incorporated in the records of tension tests upon bars, attention being paid during their tests to the subject under investigation alone.

Iron F, having been selected as suitable material, a series of tests were made in this connection, which are probably as free from erroneous results due to want of uniformity in the material, as it would be practical to procure.

Pieces were strained to tensile limit and released from strain, and periods of rest varying from one minute to six months allowed.

The results are arranged in the following table, in sequence, begining at the shortest period between tests. The test numbers are of those which were recorded in the records of tension tests upon bars:

Elevation of the limit of stress.

Experiments Nos. 13 to 59. Material, iron F. Intervals of rest after strains, varying from one minute to six months.

Test No.		Size of bar.	Strength in pounds per square inch.		Interval between tests.	Gain in strength.		Ratio of change of form at tensile limit to that at fracture.		Speed at which rupture was effected.
Bar record.	This research.		First test.	Second test.		Pounds per sq. in.	Per cent.	Reduct'n of area.	Elongation.	
		″						*Per cent.*	*Per cent.*	
663	13	1¼	50,825	51,351	1 minute	526	1.0	51	71	F.
676	14	1[illegible]	48,809	49,110	do	301	0.6	44	78	S.
661	15	1¼	49,877	50,614	3 minutes	737	1.5	50	73	M.
665	16	1[illegible]	49,024	49,637	do	613	1.3	46	67	F.
668	17	1[illegible]	49,865	50,388	do	523	1.0	51	79	S.
	18	[illegible]	49,345	49,993	1 hour	648	1.3	56	80	S.
	19	[illegible]	49,358	50,219	2 hours	861	1.7	56	85	S.
	20	[illegible]	49,459	51,362	3 hours	1,903	3.8	....	....	S.
	21	[illegible]	49,484	51,546	4 hours	2,062	4.2	....	....	S.
	22	[illegible]	49,401	51,561	5 hours	2,160	4.3	50	85	S.
	23	[illegible]	49,206	51,996	6 hours	2,790	5.6	56	83	S.
	24	[illegible]	50,257	52,886	7 hours	2,629	5.0	52	82	S.
	25	[illegible]	50,013	52,572	8 hours	2,559	5.0	54	80	S.
560	26	1[illegible]	50,840	55,037	1 day	4,697	9.2	50	80	M.
562	27	1[illegible]	49,705	55,448	do	5,743	11.5	49	75	M.
564	28	1[illegible]	51,154	55,941	do	4,787	9.3	50	75	M.
566	29	1[illegible]	51,235	55,950	do	4,715	9.2	62	80	M.
568	30	1¼	50,342	53,044	do	2,702	5.8	50	79	M.
669	31	1	51,536	60,631	3 days	9,095	17.6	53	74	S.
660	32	1¼	49,935	58,251	do	8,316	17.0	58	80	S.
655	33	1	51,536	60,631	do	9,095	17.6	49	85	S.
664	34	1[illegible]	49,175	57,635	do	8,460	17.2	56	76	S.
667	35	1[illegible]	49,267	58,049	do	8,782	17.8	52	75	F.
676	36	1[illegible]	50,143	58,136	do	7,993	15.9	54	80	S.
673	37	1[illegible]	49,266	57,263	do	7,997	16.2	50	77	S.
674	38	1[illegible]	49,438	57,991	do	8,553	17.8	51	79	S.
675	39	1[illegible]	48,537	54,655	do	6,124	12.6	50	67	F.
677	40	2	48,597	57,081	do	8,484	17.5	61	85	M.
666	41	1[illegible]	48,853	57,443	8 days	8,590	17.6	53	76	M.
669	42	1[illegible]	50,015	59,047	do	9,032	18.0	51	83	M.
656	43	1[illegible]	50,474	59,864	18 days	9,390	18.6	65	83	S.
657	44	1[illegible]	50,178	58,314	do	8,136	16.1	66	88	S.
659	45	1[illegible]	50,165	54,749	do	4,584	9.0	57	94	F.
671	46	1[illegible]	49,676	59,184	25 days	9,508	19.1	56	79	M.
672	47	1[illegible]	49,867	55,949	42 days	6,082	12.2	54	93	F.
705	48	1	51,128	60,902	6 months	9,774	19.1	57	84	S.
706	49	1[illegible]	50,530	59,626	do	9,096	18.0	51	80	S.
707	50	1¼	49,101	57,877	do	8,776	17.8	52	79	M.
708	51	1[illegible]	48,819	56,885	do	8,066	16.6	55	79	S.
709	52	1[illegible]	51,838	57,188	do	5,350	10.3	47	75	S.
710	53	1[illegible]	49,144	58,188	do	9,034	18.3	52	78	S.
711	54	1[illegible]	48,792	57,403	do	8,611	17.2	49	95	F.
712	55	1[illegible]	49,370	58,880	do	9,510	19.4	52	78	S.
716	56	2[illegible]	49,250	58,020	do	8,770	17.7	53	76	S.
719	57	2[illegible]	47,871	58,976	do	11,050	22.6	53	83	S.
722	58	2[illegible]	46,702	54,458	do	7,756	16.6	51	78	S.
725	59	3	47,655	57,250	do	9,585	20.0	42	60	S.

Abstract from detail of tests.

Average gain in less than 1 hour	1.1 per cent. (5 tests)
Average gain in less than 8 and over 1 hour	3.8 per cent. (8 tests)
Average gain in 1 day	8.9 per cent. (5 tests)
Average gain in 3 days	16.2 per cent. (10 tests)
Average gain in 8 days	17.8 per cent. (2 tests)
Average gain in over 8 and less than 42 days	15.3 per cent. (5 tests)
Average gain in 6 months	17.9 per cent. (12 tests)
	47 tests.

Nothing is determined positively by this series of tests as regards the action of this law as affecting the ductility, for although the iron was probably of as uniform a structure as it is possible to produce with a set of bars of various diameters, yet there were differences in their characteristics, as found by various tests, which would probably affect some of the minor results in this series. Judged by the change of form alone, it would seem that the ductility of the material was slightly lessened by the rest, and perhaps it was.

But the reduction of area of the same iron as shown—

By 23 test-pieces, broken by a single continued strain, was	47.5 per cent.
By 5 test-pieces, broken after rests of 1 to 3 minutes	48.5 per cent.
By 8 test-pieces, broken after rests of 1 to 8 hours	47.2 per cent.
By 5 test-pieces, broken after rests of 1 day	46.5 per cent.
By 12 test-pieces, broken after rests of 3 to 8 days	44.5 per cent.
By 17 test-pieces, broken after rests of 18 days to 6 months	43.1 per cent.

and an examination of the records of those broken by the single continued strain reveals that there were with these, variations in reduction of area, quite as great as those which in this series seem to indicate that an increase of the period of rest lessens the ductility.

The elongation was irregular; that of those broken at first stress and of those after six months' rest coinciding at 29 per cent., while intermediates varied from 27.5 per cent. to 30 per cent.

Nos. 20 and 21 of the series were not broken upon the second test, but at the fall of the lever were removed from the machine, and rested for six days, when they were broken; No. 20 reaching an ultimate stress of 55,809 pounds per square inch, a total gain of 12.8 per cent., and No. 21 reaching 56,314 pounds, a gain of 13.7 per cent.

Reduction of strength between the ultimate reached, and breaking point.

Nos. 18, 19, 22, 23, 24, and 25 were, after reaching the tensile limit, on the second test, still further tested, thus: The lever having fallen, weights were removed until a balance took place, which balance was maintained by removal of weights while the crank was turned without cessation but slowly, and the specimens finally ruptured at strains considerably less than the original strength, thus:

Number.	Original strength.	Strength at rupture.	Loss.	
			Pounds.	Per cent.
	Pounds.	*Pounds.*		
18	49,345	42,952	6,393	12.9
19	49,358	43,049	6,309	12.9
22	49,401	42,271	7,130	14.4
23	49,206	42,364	6,842	13.9
24	50,257	42,914	7,343	14.5
25	50,018	43,121	6,892	14.2
Total	....	....	6,818	13.8

Percentage of change of form at tensile limit, to that at fracture.

At tensile limit the average reduction of area which had taken place was equal to 53 per cent. of that at rupture, and the average percentage of elongation was 80 per cent.

The average of the same percentages upon the twenty-three pieces broken by single continued strain was, of reduction of area, 49 per cent., of elongation, 78 per cent.; from which averages we deduce that at the instant of ceasing to resist an increase of stress, the reduction of area which has taken place is about *one-half*, and of elongation a little over *three-quarters*, of that which will have occurred if the metal be further strained to rupture. This we believe will not prove true if the metal is ruptured by a sudden strain, by the action of which the fractured dimensions will nearly coincide with those which would have existed at tensile limit had the piece been broken by steady strains; this was indicated by the results of an experiment with an apparatus which we devised, by which we were enabled to apply sudden strains to the specimen.

By means of a pair of spring clamps, a holder was attached to the upper and lower clamps of the dynamometer, and the stress produced by turning the crank, or some indefinite portion of it, we accumulated in the legs of this holder, and at will transferred suddenly to the specimen. The machine was imperfect, its use involved risk of injury to the dynamometer, and we made but one test with it, which was as follows:

Comparison of effect of steady and sudden strains upon change of form.

Two specimens of nearly the same dimensions were turned from iron E:
No. 1 having diameter .565″, length 2″.27.
No. 2 having diameter .565″, length 2″.25.

No. 1 was broken by steady tension, and at tensile limit its diameter was .498″; length, 2″.80. No. 2 was broken by a series of jerks, and its ruptured dimensions were, diameter, .496″; length, 2″.87, the ruptured dimensions of No. 1 being, diameter, 407″; length, 3″.00.

Comparison of elevation of limit of stress, upon irons of differing characteristics.

The first series of experiments (Nos. 1 to 12) gave indications that the operation of the law was less felt by coarse and brittle irons, and by those of a steely structure, than by those of a more fibrous, ductile texture. This was considered to be a point worthy of careful examination, and a series of comparative experiments was made upon test-pieces composed of the three varieties of iron. Thirteen pieces were prepared, five of which were of soft charcoal bloom boiler iron, five of coarse contract chain iron, and three of a fine-grained bar of iron K, a very pure iron with high tenacity. These pieces were all made of uniform proportions, and were tested to tensile limit upon the same day. They were then allowed to rest *eighteen hours* and again tested. Some were broken at this second test, others released from stress at tensile limit and further tested after varying periods of rest, as per following table:

EXPERIMENTS Nos. 60 to 62.

Effect of uniform rest upon irons of widely different character.

Test-pieces rested 18 hours.

Number and marks.	Utlimate strength.		Gain in strength.		Remarks.	
	First strain.	Second strain.	Pounds.	Per cent.		
	Pounds.	*Pounds.*				
60, boiler iron	48,600	56,500	7,900	16.0	Not broken.	
61	49,800	57,000	7,200	16.4	Broken	Average gain 15.8 per cent.
62	49,800	58,000	9,200	18.4	Broken	
63	48,100	54,400	6,300	13.1	Broken	
64	48,150	55,550	7,400	15.0	Broken	
65, contract chain	50,200	54,000	3,800	7.5	Broken	Average gain 6.4 per cent.
66	50,250	53,200	2,950	5.8	Not broken	
67	50,700	55,300	4,600	9.0	Not broken	
68	49,600	52,900	3,300	6.6	Not broken	
69	51,200	52,800	1,600	3.2	Not broken	
70, iron K	58,800	64,500	5,700	9.6	Broken	Average gain 9.4 per cent.
71	59,000	65,800	6,800	11.5	Broken	
72	56,400	60,600	4,200	7.3	Broken	

These experiments confirmed the opinion already formed, and indicate that a bridge, cable, or other structure composed of iron of either of the latter two varieties will receive comparatively slight benefit from the operation of this law, while ductile, fibrous metal, which possesses greater inherent power to resist sudden strains than does the iron of coarser nature, although the latter may be better able to resist steady stress, gains in this latter power to a greater extent by the effect of strains already withstood.

Supplemental tests of Nos. 60, 66, 67, 68, *and* 69 *of foregoing test-pieces.*

No. 60, after having been strained to the tensile limit the second time, was released from stress and retested after *one year's* rest, when its ultimate strength was found to be 59,500 pounds, a total gain of 22 per cent. upon the original strength.

No. 66 was rested for 7 hours, 41 hours, and 24 hours, and after each rest repulled to the tensile limit, with results as follows (the first two tests being included for ready comparison): Strength, first strain, 50,250 pounds; rested 18 hours, strength 53,200 pounds; rested 7 hours, strength 54,700 pounds; rested 41 hours, strength 54,500 pounds; rested 24 hours, strength 54,000 pounds.

No. 67. First strain, strength 50,700 pounds; rested 18 hours, strength 55,300 pounds; rested 7 hours, strength 53,150 pounds; rested 41 hours, strength 56,600 pounds; rested 24 hours, strength 54,000 pounds.

No. 68. First strain, strength 49,600 pounds; rested 18 hours, strength 52,900 pounds; rested 8 hours, strength 51,000 pounds; rested 16 hours, strength 54,800 pounds; rested 24 hours, strength 53,000 pounds.

No. 69. First strain, strength 51,200 pounds; rested 18 hours, strength 52,800 pounds; rested 8 hours, strength 54,900 pounds; rested 16 hours, strength 52,750 pounds; rested 24 hours, strength 51,750 pounds.

The four pieces were broken at the strains last given.

Experiments with two sets of test-pieces, one set cut from bars in their normal condition, the other from same bars after the latter had been pulled asunder by tension.

Nineteen bars of various irons were selected, and from each a cylindrical test-piece was prepared; the bars were then fitted with heads and pulled asunder. Another set of cylinders was prepared by cutting the necessary length from one of the broken ends, about six inches from the point of rupture. Both sets of cylinders were tested, with results as per following table, showing a great gain in strength in all cases when the material could be classed as wrought iron, but *none* when it was steel. Hence we infer that excess of carbon deprives iron of the power to gain strength through the action of this law.

EXPERIMENTS Nos. 73 to 94.

Comparison of strength of two sets of test-pieces, the first of which was cut from bars in their normal condition, and the second from the same bars, after the latter had been pulled in two.

Number of test.	Size of bar.	Name of iron.	Stress required to break the test-pieces.		Strength of second set over first.	
			First set.	Second set.	Pounds.	Per cent.
	"		*Pounds.*	*Pounds.*		
73	$1\frac{3}{8}$	K.	53, 520	72, 700	19, 180	35. 8
74	$1\frac{11}{16}$	K.	53, 920	71, 800	17, 880	33 1
75	$1\frac{13}{16}$	C.	47, 875	63, 560	15, 685	32. 7
76	$1\frac{1}{4}$	C.	48, 600	65, 000	16, 400	33. 7
77	$1\frac{5}{8}$	C.	56, 000	73, 000	17, 000	30. 3
78	$1\frac{3}{4}$	C.	52, 000	67, 900	15, 900	30. 6
79	$1\frac{7}{16}$	C.	45, 800	63, 300	17, 500	36. 0
80	$1\frac{11}{16}$	B.	51, 900	72, 000	20, 100	38. 7
81	$1\frac{13}{16}$	B.	53, 600	68, 700	15, 100	28. 1
82	$1\frac{1}{4}$	J.	50, 350	68, 400	18, 050	35. 8
83	$1\frac{5}{8}$	J.	50, 400	67, 700	17, 300	34. 3
84	$1\frac{3}{8}$	F.	50, 180	66, 400	16, 220	32. 3
85	$1\frac{5}{8}$	F.	50, 400	67, 200	16, 800	33. 3
86	$1\frac{1}{4}$	E.	50, 080	68, 000	17, 920	35. 7
87	$1\frac{1}{8}$	E.	50, 100	70, 100	20, 000	39. 9
88	$1\frac{13}{16}$	L.	58, 390	69, 200	10, 810	18. 5
89	$1\frac{3}{8}$	L.	59, 290	67, 160	7, 870	13. 2
90	$1\frac{5}{8}$	L.	75, 233	76, 600	....	....
91	$1\frac{3}{8}$	L.	84, 800	....	....	....
92	$1\frac{3}{8}$	L.	74, 600	72, 600	....	....
93	$1\frac{7}{16}$	L.	66, 500	....	....	....
94	$1\frac{7}{16}$	L.	66, 800	73, 900	5, 250	7. 9

The test-pieces from Nos. 73 to 89, inclusive, were made from ordinary commercial bar iron of various degrees of ductility. All show a remarkably great gain in strength, caused by the tension upon the entire bars.

The interval of time between the two sets of tests was not noted, but it was several days.

There is no marked difference in the amount of elevation, except upon the test-pieces made from L, which was a weld steel, although sent to us as chain iron. With this metal the results were exceedingly irregular, and it was thought advisable to make a few careful tests upon it. Four pieces were therefore prepared from a bar of $\frac{5}{8}''$ diameter, which were tested to the tensile limit, then rested for one hour, one day, one week, and one month, respectively, when they were retested with results as follows:

Experiments Nos. 95 *to* 98, *inclusive. Material, weld steel.*

Number.	Original dimensions.		Strength at—		Period of rest.	Gain in strength.	
	Diameter.	Length.	First test.	Second test.		Pounds.	Per cent.
	In.	*In.*	*Pounds.*	*Pounds.*			
95	. 500	2. 25	59, 078	58, 619	One hour	— 459	....
96	. 500	2. 25	58, 569	57, 805	One day	— 764	....
97	. 496	2. 25	59, 000	59, 653	One week	+ 653	1
98	. 501	2. 25	59, 859	61, 694	One month	+1, 834	3

The entire series of tests by tension upon this metal indicates such irregularity in its strength that the foregoing tests do not possess a positive value, but they *indicate* that there is a great difference between the action of weld steel and even steely irons, still greater between it and fibrous iron when examined in reference to the action of this law. We obtain no positive evidence that any increase of strength is caused in steel by rest after strain.

MISCELLANEOUS EXPERIMENTS.

We had found that in one minute of rest there was an appreciable gain; it was determined to ascertain still more closely how quickly this law would begin to operate; also how often it could be expected to act between the points of ultimate strength and rupture, hoping that the results would furnish data by which the effect of repeated alternations of strains and rests might be judged. To this end a number of test-pieces were strained to tensile limit, the weights then removed, no addition being made to the stress until a balance took place; the dimensions were measured at the instant of balance and the stress at balance recorded; the strain was then reapplied, the lever first rising and then falling. The operation was repeated, with results as follows:

EXPERIMENT No. 1.

Test-piece, iron L; ¾"; diameter, .696"; length, 2".80.

	Stress at—		Dimensions.	
	Lever-fall.	Balance.	Diameter.	Length.
	Pounds.	*Pounds.*	*In.*	*In.*
	25, 280			
1st balance		24, 400	.596	3. 24
1st elevation	25, 225			
2d balance		24, 620	.592	3. 27
2d elevation	25, 050			
3d balance		24, 475	.585	3. 275
3d elevation	25, 000			
4th balance		24, 400	.580	3. 28
4th elevation	24, 925			
5th balance		Lost	.570	3. 31
5th elevation	24, 625			
6th balance		24, 000	.566	3. 312
6th elevation	24, 550			
7th balance		24, 000	.564	3. 32
7th elevation	24, 425			
8th balance		23, 950	.560	3. 325
8th elevation	24, 250			
9th balance		23, 850	.555	3. 33
9th elevation	24, 200			
10th balance		23, 800		
10th elevation	24, 250			
11th balance		23, 750	.558	3. 35
11th elevation	24, 140			
12th balance		23, 700	.548	3. 35
12th elevation	24, 000			
13th balance		23, 580	.547	3. 35
13th elevation	23, 900			
14th balance		23, 450	.545	
14th elevation	23, 840			
15th balance		23, 350		
15th elevation	23, 750			
16th balance		23, 250	.537	3. 36
16th elevation	23, 660			
17th balance		23, 050	.530	
17th elevation	23, 450			
18th balance		22, 900	.525	3. 365
18th elevation	23, 180			
19th balance		22, 550	.517	3. 37
19th elevation	23, 000			
20th balance		22, 875	.512	
20th elevation	22, 760			
21st balance		22, 125	.510	
21st elevation	22, 600			
22d balance		22, 000	.503	
Broke	22, 300		.500	

EXPERIMENT No. 2.

Test-piece, iron L; ¾″; diameter, .724″; length, 2″.78.

	Stress at—		Dimensions.			Stress at—		Dimensions.	
	Lever-fall.	Balance.	Diameter.	Length.		Lever-fall.	Balance.	Diameter.	Length.
	Pounds.	*Pounds.*	*In.*	*In.*		*Pounds.*	*Pounds.*	*In.*	*In.*
	26,375				7th elevation	24,900			
1st balance		25,525	.630	3.18	8th balance		24,125	.572	
1st elevation	26,300				8th elevation	24,620			
2d balance		25,450	.624	3.19	9th balance		23,750	.562	3.28
2d elevation	26,125				9th elevation	24,240			
3d balance		25,300	.612	3.21	10th balance		23,375	.555	3.30
3d elevation	25,950				10th elevation	23,860			
4th balance		25,075	.604		11th balance		23,100	.548	
4th elevation	25,740				11th elevation	23,625			
5th balance		25,000	.598		12th balance		22,900	.540	
5th elevation	25,525				12th elevation	23,250			
6th balance		24,700	.590	3.25	13th balance		22,550	.535	
6th elevation	25,175				Broke	22,900		.505	3.32
7th balance		24,400	.580						

EXPERIMENT No. 3.

Test-piece, iron L; ⅞″; diameter, .806″; length, 3″.

	Stress at—		Dimensions.			Stress at—		Dimensions.	
	Lever-fall.	Balance.	Diameter.	Length.		Lever-fall.	Balance.	Diameter.	Length.
	Pounds.	*Pounds.*	*In.*	*In.*		*Pounds.*	*Pounds.*	*In.*	*In.*
	31,500				6th balance		30,275	.670	3.74
1st balance		30,850	.699	3.70	6th elevation	30,960			
1st elevation	31,375				7th balance		30,050	.665	Lost.
2d balance		30,740	.696		7th elevation	30,810			
2d elevation	31,320				8th balance		30,000	.663	3.76
3d balance		30,675	.692	3.73	8th elevation	30,625			
3d elevation	31,325				9th balance		29,900		
4th balance		30,650	.685		9th elevation	30,500			
4th elevation	31,200				10th balance		29,775	.656	3.78
5th balance		30,400	.679		10th elevation	30,350			
5th elevation	31,120				Broke	26,700		.542	3.92

EXPERIMENT No. 4.

Test-piece, iron K; diameter, .976″; length, 3″.08.

	Stress at—		Dimensions.			Stress at—		Dimensions.	
	Lever-fall.	Balance.	Diameter.	Length.		Lever-fall.	Balance.	Diameter.	Length.
	Pounds.	*Pounds.*	*In.*	*In.*		*Pounds.*	*Pounds.*	*In.*	*In.*
	41,550				5th elevation	40,850			
1st balance		40,460	.868	3.86	6th balance		39,575		
1st elevation	41,500				6th elevation	40,450			
2d balance		40,400			7th balance		39,450		
2d elevation	41,430				7th elevation	40,000			
3d balance		40,200	.857	3.89	8th balance		38,575		
3d elevation	41,350				8th elevation	38,600			
4th balance		39,900	.850	3.93	9th balance		35,200		
4th elevation	41,000				Broke	34,200			
5th balance		39,700	.840	3.95					

EXPERIMENT No. 5.

Test-piece, iron F; diameter, .800"; length, 3".50.

	Stress at—		Dimensions.			Stress at—		Dimensions.	
	Lever-fall.	Balance.	Diameter.	Length.		Lever-fall.	Balance.	Diameter.	Length.
	Pounds	Pounds	In.	In.		Pounds	Pounds	In.	In.
	32, 275				12th balance		30, 300	.732	4. 36
1st balance		31, 500	.786	4. 26	12th elevation	31, 000			
1st elevation	32, 250				13th balance		30, 300	.728	
2d balance		31, 450	.784		13th elevation	30, 825			
2d elevation	32, 175				14th balance		30, 217		
3d balance		31, 470	.775		14th elevation	30, 570			
3d elevation	32, 100				15th balance		29, 550	.714	
4th balance		31, 150	.772	4. 30	15th elevation	30, 300			
4th elevation	32, 000				16th balance		29, 600	.705	
5th balance		31, 150	.767		16th elevation	30, 000			
5th elevation	32. 050				17th balance		29, 400	.702	
6th balance		31, 300	.764		17th elevation	29, 840			
6th elevation	32, 000				18th balance		29, 000	.697	
7th balance		31, 100	.760	4. 32	18th elevation	29, 600			
7th elevation	31, 820				19th balance		29, 000	.691	
8th balance		30, 900	.756	4. 34	19th elevation	29, 325			
8th elevation	31, 750				20th balance		28, 650	.686	
9th balance		30, 850	.752		20th elevation	29, 000			
9th elevation	31, 475				21st balance		28, 450	.678	
10th balance		30, 900			21st elevation	28, 700			
10th elevation	31, 375				22d balance		28, 000	.675	
11th balance		30, 700	.740		Broke	28, 325		.652	4. 47
11th elevation	31, 125								

EXPERIMENT No. 6.

Test-piece, iron F; diameter, .897"; length, 3".50.

	Stress at—		Dimensions.			Stress at—		Dimensions.	
	Lever-fall.	Balance.	Diameter.	Length.		Lever-fall.	Balance.	Diameter.	Length.
	Pounds	Pounds	In.	In.		Pounds	Pounds	In.	In.
	38, 560				12th elevation	37, 200			
1st balance		37, 225	.786	4. 30	13th balance		36, 520	.750	4. 39
1st elevation	37, 880				13th elevation	37, 000			
2d balance		37, 000	.785		14th balance		36, 225	.746	4. 40
2d elevation	37, 650				14th elevation	36, 740			
3d balance		36, 950	.781	4. 32	15th balance		36, 000	.741	
3d elevation	37, 600				15th elevation	36, 550			
4th balance		36, 925			16th balance		35, 900	.738	
4th elevation	37, 650				16th elevation	36, 375			
5th balance		36, 940	.780		17th balance		35, 600	.732	4. 43
5th elevation	37, 640				17th elevation	36, 020			
6th balance		36, 950	.778		18th balance		35, 200	.728	
6th elevation	37, 700				18th elevation	35, 850			
7th balance		37, 000	.776		19th balance		35, 000	.725	
7th elevation	37, 750				19th elevation	35, 550			
8th balance		37, 000	.775		20th balance		34, 750	.720	
8th elevation	37, 770				20th elevation	35, 250			
9th balance		37, 025	.765	4. 36	21st balance		34, 525	.716	4. 45
9th elevation	37, 700				21st elevation	35, 000			
10th balance		37, 000	.760		22d balance		34, 250	.718	4. 46
10th elevation	37, 580				22d elevation	34, 825			
11th balance		36, 800	.758		23d balance		34, 200	.710	
11th elevation	37, 400				23d elevation	34, 575			
12th balance		36, 000	.754		Broke		33, 800	.688	4. 48

The lever remained at a steady balance at 37.225 pounds, the yield of the specimen exactly counterpoising the increase of the strain, which was produced by the crank being turned 50 revolutions per minute for nearly four minutes, during which period the diameter reduced from .806″ to .786″, and the length increased from 4″.17 to 4″.30.

We were thus furnished with valuable confirmation of views previously expressed as to the amount of entire change of form which has taken place at tensile limit. In this case the percentage of entire reduction of area at rupture, which had occurred at beginning of balance, was 39 per cent., at end 48 per cent.; of elongation at beginning 65 per cent., at end 77 per cent. No 6 experiment was upon a test-piece which had been strained to the tensile limit two months previously; at that time the first stretch took place at a stress equal to 37,880 pounds per square inch and the strength at tensile limit was 51,946 pounds.

Upon this second test the tensile strength was 61,022 pounds per square inch and the stress producing the first stretch was coincident with the ultimate strength.

The description in detail of one of these experiments will answer for all. Selecting, therefore, No. 1, it is as follows:

At a stress of 24,000 pounds the lever's movement upward had become very slow, and although the crank was turned continuously, it required over six minutes to rise to 25,275 pounds, the 24,000 pounds having been reached in about eight minutes. From 25,275 to 25,280 pounds the lever slowly vibrated over five minutes, then settled to rest, the latter figure being the highest point reached, equal to a tenacity of 66,426 pounds per square inch. When the lever fell, the stress was stopped, weights removed until the scale marked 24,400 pounds—a removal of 880 pounds, when the lever rose slowly to a balance, the marks coinciding. At this instant the measurements (diameter .596″, length 3″.24) were taken, the operation requiring about 25 seconds; strain was then reapplied and the lever instantly rose till it required 25,225 pounds, an addition of 825 pounds, to keep the balance, it then sunk rapidly. This operation was repeated twenty-two times, the gain in strength constantly decreasing and the loss increasing, until rupture finally took place at 22,300 pounds; a loss of nearly 3,000 pounds on the original strength.

Stress required to produce successive changes of form.

The stress which produced the first perceptible elongation, and that which increased the same each *tenth* of an inch, also the corresponding reduction of diameter, was observed, and are shown in the following tables:

No. 1. *Tenacity*, 66,246 *pounds.*

Stress of 44,000 lbs. per sq. inch produced elongation .01″, reduced diameter .016″
Addition of 12,600 lbs. per sq. inch increased elongation to .10″, reduced diameter to .032″
Addition of 7,500 lbs. per sq. inch increased elongation to .20″, reduced diameter to .048″
Addition of 1,700 lbs. per sq. inch increased elongation to .30″, reduced diameter to .066″
Addition of 300 lbs. per sq. inch increased elongation to .40″, reduced diameter to .087″
Addition of 25 lbs. per sq. inch increased elongation to .44″, reduced diameter to .100″

No. 2. *Tenacity*, 63,880 *pounds.*

Stress of 40,500 lbs. per sq. inch produced elongation .02″, reduced diameter .002″
Addition of 14,540 lbs. per sq. inch increased elongation to .12″, reduced diameter to .019″
Addition of 7,260 lbs. per sq. inch increased elongation to .22″, reduced diameter to .044″
Addition of 1,630 lbs. per sq. inch increased elongation to .32″, reduced diameter to .068″
Addition of 133 lbs. per sq. inch increased elongation to .40″, reduced diameter to .094″

No. 3. *Tenacity,* 61,740 *pounds.*

Stress of 36,064 lbs. per sq. inch produced elongation .01", reduced diameter .002"
Addition of 9,408 lbs. per sq. inch increased elongation to .11", reduced diameter to .012"
Addition of 10,368 lbs. per sq. inch increased elongation to .21", reduced diameter to .030"
Addition of 3,920 lbs. per sq. inch increased elongation to .31", reduced diameter to .046"
Addition of 1,314 lbs. per sq. inch increased elongation to .41", reduced diameter to .064"
Addition of 519 lbs. per sq. inch increased elongation to .51", reduced diameter to .078"
Addition of 147 lbs. per sq. inch increased elongation to .58", reduced diameter to .102"

No. 5. *Tenacity,* 51,880 *pounds.*

Stress of 36,166 lbs. per sq. inch produced elongation .02", reduced diameter .002"
Addition of 6,424 lbs. per sq. inch increased elongation to .12", reduced diameter to .016"
Addition of 4,588 lbs. per sq. inch increased elongation to .22", reduced diameter to .023"
Addition of 2,492 lbs. per sq. inch increased elongation to .32", reduced diameter to .038"
Addition of 1,352 lbs. per sq. inch increased elongation to .42", reduced diameter to .054"
Addition of 608 lbs. per sq. inch increased elongation to .52", reduced diameter to .069"
Addition of 250 lbs. per sq. inch increased elongation to .62", reduced diameter to .084"
Addition of unknown amount increased elongation to .71", reduced diameter to .104"

Thus it is evident that after the elastic limit has been reached, a slight addition to the stress produces very disproportionate effect. As a confirmation, our tests of cable show in one case that an elongation of 25" produced by 56 tons stress, was increased to 56" by the addition of 12 tons.

In obtaining the stress which produced the elongation of each tenth of an inch we watched for the elongation and stopped the strain the instant the looked-for tenth had taken place. The experiment was varied in the following manner, with two test-pieces, made from soft charcoal-bloom boiler iron.

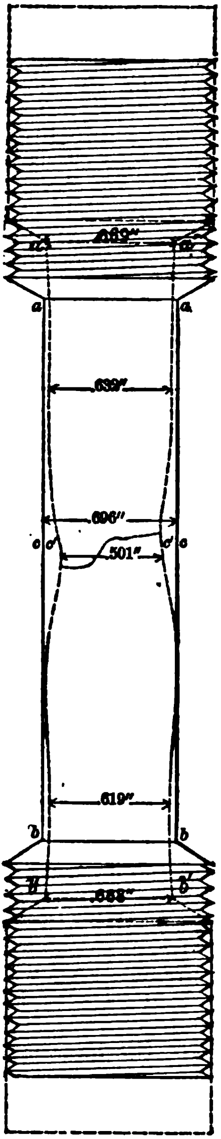
With these, having obtained the first stretch, we applied slowly an additional stress of 1,000 pounds, and measured the dimensions, then continued to add the same, measuring after each addition, until the lever fell indicating tensile limit. We thus procured data as to the action of the metal between the elastic and the tensile limit, the former tests Nos. 1, 2, 3, and 5 having begun at the latter period.

Experiments to determine the effect in changing form, of stress increasing from the elastic to the tensile limit, gradually applied.

Test-pieces of soft charcoal-bloom iron.

Stress on test-piece.	No. 1.				No. 2.			
	Dimensions.		Change.		Dimensions.		Change.	
	Diameter.	Length.	Red. of diam.	Elon.	Diameter.	Length.	R. D.	E.
	"	"	"	"	"	"	"	"
None	1.000	3.938	....	....	0.996	4.008	....	....
20,500 pounds	.995	3.956	0.005	0.018	0.989	4.038	0.007	0.030
22,000 pounds	.994	3.985	0.001	0.029	0.988	4.067	0.001	0.029
23,000 pounds	.992	4.001	0.002	0.016	0.985	4.076	0.003	0.009
24,000 pounds	.991	4.010	0.001	0.009	0.983	4.093	0.002	0.017
25,000 pounds	.989	4.024	0.002	0.014	0.982	4.109	0.001	0.016
26,000 pounds	.987	4.040	0.002	0.016	0.980	4.121	0.002	0.012
27,000 pounds	.985	4.058	0.002	0.018	0.977	4.242	0.003	0.021
28,000 pounds	.983	4.078	0.002	0.020	0.975	4.265	0.002	0.023
29,000 pounds	.980	4.099	0.003	0.021	0.972	4.280	0.003	0.015
30,000 pounds	.977	4.124	0.003	0.025	0.971	4.305	0.001	0.025
31,000 pounds	.975	4.156	0.002	0.032	0.967	4.340	0.004	0.035
32,000 pounds	.972	4.168	0.003	0.032	0.965	4.374	0.002	0.034
33,000 pounds	.968	4.201	0.004	0.033	0.959	4.402	0.006	0.028
34,000 pounds	.964	4.239	0.004	0.038	0.955	4.454	0.004	0.052
35,000 pounds	.960	4.284	0.004	0.045	0.948	4.514	0.007	0.060
36,000 pounds	.955	4.339	0.005	0.055	0.938	4.586	0.010	0.072
37,000 pounds	.943	4.425	0.012	0.086	0.921	4.658	0.017	0.072
38,000 pounds	.933	4.501	0.010	0.076	....	....	....	....

While testing the piece whose history is given as Experiment No. 1 we noticed after rupture that, in addition to the reduction at the point of rupture, where the taper was very abrupt, there were several other places much reduced, as shown in cut. No test-piece from other irons manifested this peculiarity; two others of this material "iron L" did.



This irregular decrease of diameter under tension was considered to be an indication that the strength of the material, however great it might occasionally prove, was very irregular, that each bar contained both strong and weak spots, and that it was thus unsuitable for cables.

SECTION V.

IMPACT.

A PAPER DESCRIBING A SERIES OF TESTS MADE BY THE APPLICATION OF SUDDEN STRAINS TO PORTIONS OF THE VARIOUS BARS, WHOSE ACTION UNDER TENSION HAS BEEN GIVEN.

The tests by which we ascertain the powers of the various irons of the series to resist steady tensional strains, applied in the direction of the fiber, and when manufactured into links, furnish us with no data by which their relative powers to resist sudden strains, applied transversely, can be judged. As cables are more frequently broken by strains of this nature than by all other causes combined, it was considered to be absolutely necessary that the series should be subjected to such tests as would develop their relative values in this respect before we could express an opinion as to which of the varying characteristics, as developed by tension alone, indicated that the iron in which they existed could be considered as in every way suitable for the manufacture of cables.

Having no apparatus by which such tests could be made, one was devised by the chairman of this committee, by the use of which we were enabled to form a very fair judgment as to the *comparative* values of the irons when subjected to shocks.

This machine was called the impact-hammer, and it is shown in the accompanying lithograph.

METHOD OF TESTING BY IMPACT.

Our method of testing by this machine was this: Test-pieces not less than twelve diameters in length were placed across the hole through the anvil, the centers being directly under the edge of the wedge-shaped hammer, which was raised to various heights and allowed to drop upon them.

Bars of some irons which were tested by this method could, while in their normal condition, the skin being in no manner nicked or weakened, be broken in two by blows of less than 30 feet drop; with other irons it was necessary to weaken them by a circular score $\frac{1}{32}''$ deep that we might succeed in breaking the test-piece, it not being convenient to use a hammer of over 100 pounds weight, which could be hoisted but 30 feet. This cut through the skin reduced the bar's power to resist, in the same manner that it is reduced by the ordinary method of nicking with a cold chisel, and the blows of the hammer were of the same nature as those given by sledge hammers; but with this machine the force of the blow could be regulated and known, and the weakening produced by the cuts made uniform.

The wedge-shaped portion of the hammer permitted a bar to bend to an angle of 120°.

The energy of the blow delivered by this hammer may be deduced from the formula $E=\frac{wv^2}{2g}$, in which w = weight of hammer in pounds, v = its velocity in feet, g = gravity (at Washington 32,153), and E = energy in foot pounds.

By resolving this formula, it will be seen that for each foot of drop of the hammer the energy is equal to 100 foot pounds. As, however, the

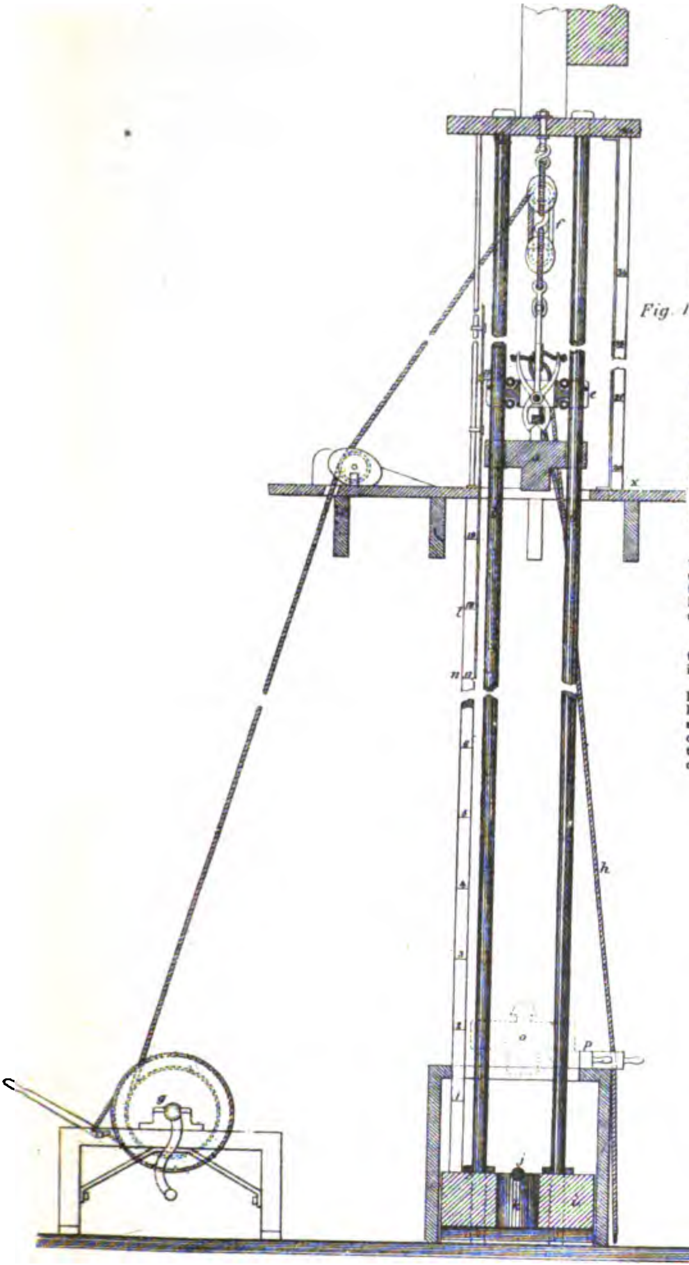


Fig. 1

Description.

A cast-iron hammer having a wedge-shaped impact surface upon its lower side (Fig. 2) is made to traverse two perpendicular iron rods, of say 2½ inches diameter and from 30 to 50 feet in length, which pass through holes in the body of the hammer, as shown at a (Fig. 1).

The hammer may be of any weight, a convenient one being 100 pounds.

A traveler of wood or metal, fitted with a pair of hooks which can be opened or closed by pulling up a cord (*h*) attached to them, is placed upon the rods above the hammer, as shown at *e* (Fig. 1). At the foot of the rods, they passing through it, as shown at *i*, a heavy cast-iron block with a cylindrical opening (*k*) eight inches in diameter is fitted; the specimen of iron to be tested (*j*) is placed across this circular hole, the hammer resting upon the box which surrounds the anvil, to prevent accidents, as shown by dotted lines (*o*), and supported by a chock (*p*).

A common purchase (shown at *f*), through which a hoisting rope is led to the windlass (*g*), is secured to the upper portion of the framework.

At the side of one of the rods an upright, marked plainly to feet and inches (*l*), is secured.

Should it be necessary to carry the rods through a flooring, as shown at *x* (Fig. 1), a slight projection on the upper surface of the traveler (shown at *m*) is fitted to come in contact with and operate a light rod which has on its lower end a pointer (*n*).

To use the machine, the traveler is lowered until the clip-hooks clasp a projection on top of the hammer; the latter is then hoisted to the desired height, the lower edge of the hammer being brought in line with the figure on the measuring rod.

Should the hammer be hoisted out of sight, through a floor, the marker (*n*) will indicate its height.

When at the proper height, the tripping-line (*h*) is pulled, opening the hooks, and releasing the hammer, which falls, striking the specimen (*j*) in the centre a blow whose force can be measured, and which is dependent upon the gravity of the location, and slightly decreased by the friction.

Fig. 2.

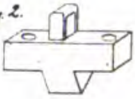
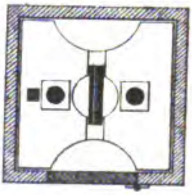


Fig. 3.



AM. PHOTO-LITHO. CO. N.Y. (OSBORNE'S PROCESS.)

Impact Hammer

dynamical effect of the blows are necessarily modified by friction and other causes, among which is the increasing distance of the drop, as the specimen yields, and as the power to resist these blows must be reduced by the effect of those previously sustained by the specimen under test, our results by the use of this machine have but a slight and indirect value from a scientific point of view; but, furnishing us as they did with an unerring method by which we could judge whether an iron was or was not tough enough to make good chain cables, also with indications which enabled us to form a judgment upon the same point by the results of tensional tests, they were very valuable for our purposes.

Through results obtained, by its use, nearly all of the chain cable on hand, owned by the Navy Department, was condemned, and the endeavor to make an iron which could withstand the severe tests given by this machine, resulted in the discovery of the process by which the experimental cable iron (hammered iron and iron A) was produced.

Through the data collected by the test by this method of a large number of bars of various irons differing widely in character, we were able to detect the existence of a connecting link, and partially trace its course, between characteristics displayed under tension and those produced by impact.

Iron with high tensile strength generally proved to be possessed of but comparatively low resilience; it would break under the blows with but slight deflection, and leave a fractured surface, smooth as though the bar had been cut in two by a sharp knife, the ends of the fibers showing, like steel, a fine, slightly granulous surface.

Iron of coarse, slightly-worked character would have an equally smooth and bright surface, but the coarse, granulous appearance of the cut fibers denoted how slightly they had been affected by the rolls.

Iron with a high elastic limit would resist the first blow with but little injury or deflection, but the deflection once started by subsequent blows, it would yield more at each than would other irons with a lower limit, which were more affected by the first blow. Some irons would, after having been weakened by the cicrular cut through the skin, resist with slight injury blows which would break in two bars of the same size of other irons which had not been so weakened.

There are many irons valuable for many purposes, which would not yield good results under this form of test; but however valuable for other purposes, the material which proves brittle under this test cannot be expected when made into cable, and subjected to strains of a similar nature, to prove equal to its tasks.

Iron which is materially weakened by a repetition of slight sudden strains, none of which produce preceptible injury, but which do so injure it that eventually a strain no greater, and perhaps much less, than those previously encountered will destroy it, is not suitable for cable. Iron whose entire strength depends upon its remaining perfectly free from abrasion or slight cracks is not suitable for cables. Our tests by impact revealed that large quantities of iron possessing the above defects had been accumulated by the government, all having passed satisfactorily the examinations, which consisted of tension-tests made upon test-pieces of erroneous proportions. Much of this iron was of good material, but the low price at which it had to be supplied in order that the *lowest bidder* should, as the law directed, receive the contract, had necessitated that, in order to make it cheap enough, but very little work should be expended upon it.

Our experiments demonstrated not only its want of value in its present state, but that also by thorough work it could be vastly improved, and when, in addition to this work, material of no greater cost, but possessing qualities that the coarse chain iron lacked was added, we found that most valuable iron, capable of resisting all strains, was produced.

An example of such a transformation will be described. The material selected was taken from the pile of $2\frac{3}{16}''$ chain iron, and was probably as inferior a bar of iron as could be found in the pile, or in our markets, there being in the stock of chain iron, however, a great many equally as poor.

These bolts, each over 26″ long, were thoroughly tested. Several which had not been weakened by a score were broken square in two by a single blow of the hammer dropped 25 to 30 feet; others, after having been struck from ten to twenty times by the hammer from a height of 8 or 10 feet, and showing no injury or deflection, would, upon receiving another blow of no greater force, break in two; other bars scored as has been described would break in two at single blows of from 1 to 3 feet drop.

In all cases the appearance of the fracture was the same, and is shown in Fig. 1, Plate VI, and would be described as "bright, coarse granulous." The piece photographed was broken by a single blow of the hammer dropped *three* feet.

The fragments of this bar, with those of several others of the same lot, some of which had broken by even lighter blows, were piled with alternate layers of *old boiler iron* (they having been first thoroughly reworked), and were hammered into a bloom, from which a bar of 2″ diameter was swaged. This was cut into pieces 24″ long, and the pieces were scored in two places 8″ apart, and then tested as was the original bar, except that each drop of the hammer was from a height of *thirty feet.* The first score received *ten* such blows before it was entirely torn in two, and the fractured surface appeared as shown in Fig. 2 of same plate.

This bar was still further tested to ascertain the effect of low temperature upon the strength of an iron of this description. After exposure for twenty-four hours in the open air, the temperature averaging about 30° Fah., the second score was subjected to impact and resisted *eight* blows of 30 feet drop, the ninth blow cutting in two the remaining segment at the top, which developed a fine granulous appearance, as shown at *b*, Fig. 1, Plate III.

The resemblance of the segment of *b* to the entire face of Fig. 1, Plate VI, and to the same in *a*, Plate III, is caused by the fact that in each case the blow which produced the effect was so far beyond the power of the iron to resist, that the fibers were *cut* in two, as if struck with a chopping-knife.

With the 2″ bar the test was a 30 feet drop upon about $\frac{1}{4}''$ of thickness which had already been weakened by the shock of eight as heavy blows. With the $2\frac{3}{16}''$ the test was but 3 feet drop, delivered upon a bar over $2\frac{1}{4}''$ thick which had sustained no previous stress. There is between them a difference that the illustration does not show clearly. In both cases the fibers are cut across at right angles, and show by the fineness of the bright ends in the 2″ bar that the material was good; in the other bar the ends of the fibers are coarse and large. The brightness of the first resembles to a certain extent that of fractured steel; that of the other, fractured cast iron.

The fracture shown at *a*, Fig. 1, Plate III, is that of another made upon the same 2″ bar, which had withstood the extreme tests described. In this case, however, the score was cut much deeper, and weights being

PLATE III.
IMPACT TESTS.

FIG. 1.

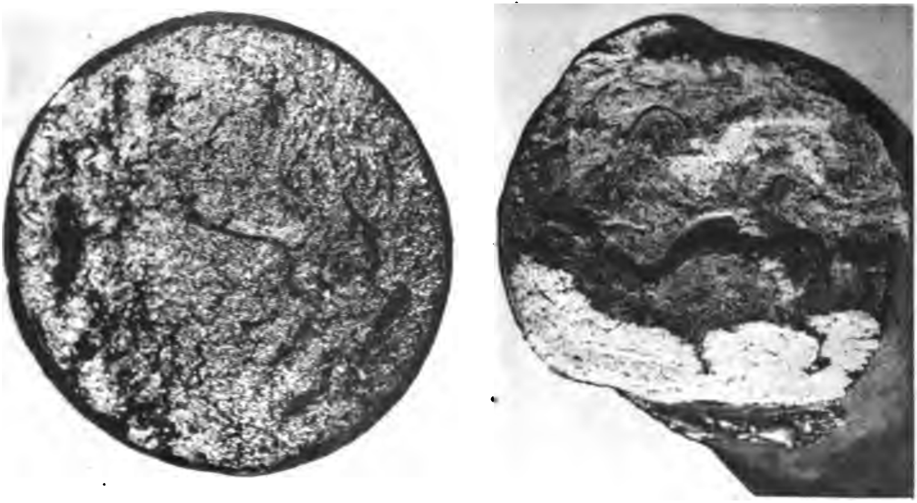
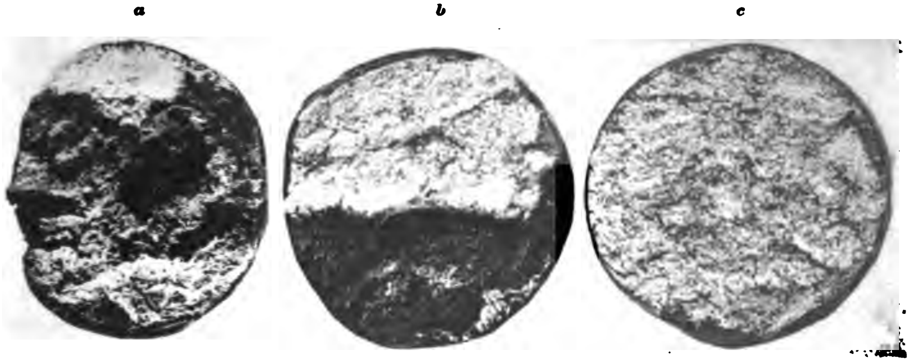


FIG. 2,



Heliotype Printing Co., 211 Tremont Street, Boston.

DIFFERENCE IN APPEARANCE OF FRACTURES PRODUCED BY IMPACT, OF VARYING DEGREES OF ENERGY, THE MATERIAL BEING THE SAME.

PLATE IV.
IMPACT TESTS.

FIG. 1.

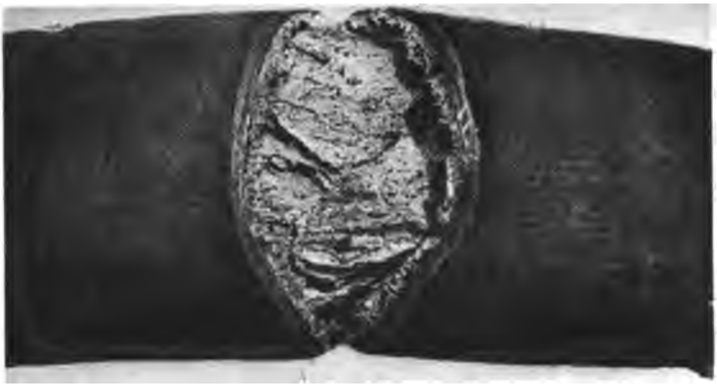
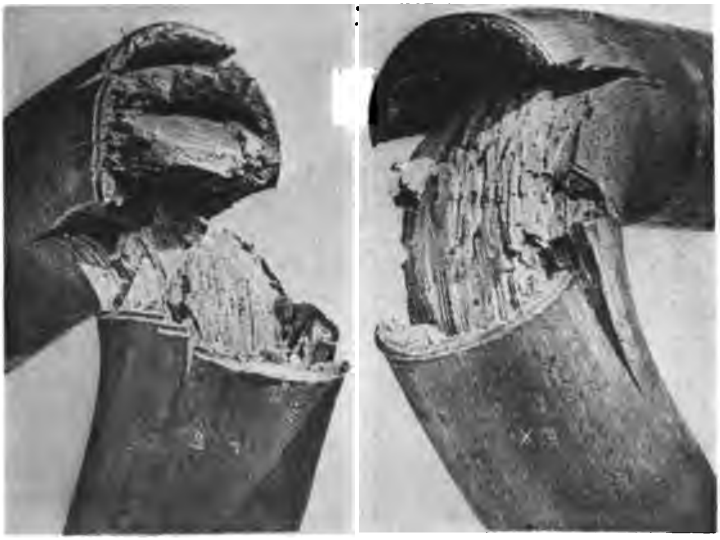


FIG. 2.



Heliotype Printing Co., 211 Tremont Street, Boston.

THE PHENOMENA OF "BARKING" AS MANIFESTED BY IRON A (FIG. 1), AND IRONS F AND Fx (FIG. 2).

added to the hammer, the test-piece received a blow equal to 6,000 foot pounds, which cut it in two, as shown.

The extreme difference between the appearance of the fractures made upon the same material (and it of great resisting powers), by different degrees of the same force, indicates that it is unsafe even for an expert to attempt to give evidence as to the character of the material from which a bridge, axle, or cable that has been accidentally broken, was made, unless he knows just *how* it was broken. To render a judgment upon this point a person must not only be an expert, but he must know by what character and amount of force the fracture was produced.

The fractures illustrated in Fig. 2, Plate III, supply additional evidence. The three were made by impact upon the same bar (of iron A, 1¼″ diameter), which was scored in three places, 8 inches apart. At *a* the score was slight, and the piece was torn in two by repeated light blows.

At *b* the score was the same, but after the bar had been broken half in two by light blows, one heavy one was given, which *cut* in two the remainder.

At *c* the score was deep, and one heavy blow did the work; *a* would be described as "all fibrous"; *b* as "half granulous and half fibrous"; *c* as "bright granulous."

The illustrations given in Plate VI may be considered as representing typical fracture by impact of thoroughly worked and of insufficiently worked irons. The first will bend before it breaks; the second will break without bending.

Irons F, F*x*, O, D, H, G, P*x*, and some of the bars of B, C, and P, resemble more or less in their characteristics those shown in Fig. 2; those of irons N, the 2″ bar of D, and some of those of B and C, resemble Fig. 1, as did most of the contract chain iron.

Reference has been made to the remarkable difference which existed between the 2″ bars of iron D and the smaller bars of the same iron. No description can mark this difference as plainly as a photograph, and such photograph was accordingly prepared. (See Plate X.)

In the first pair of fractures, the contrast between the 2″ bar and a smaller one, as developed by impact, is given. The 2″ bar was, after being scored, broken by a single *twenty-foot* drop of the hammer, showing no deflection. The 1⅝″ bar was but slightly cracked by a blow of the same force, and received four others of from 5 to 8 feet drop before rupture was complete.

The second pair show the action under tension of the 2″ and 1¾″ bars of the same lot, the former showing but slight reduction of area (2.1 per cent.), and its fractured surface resembling very closely that of the fracture made by impact, the latter reducing 49.7 per cent., showing a fibrous surface.

BARKING.

A peculiar phenomenon occurred with irons of a certain type during the test by impact, which was given the shop name of "barking." Illustrations in Plates IV and XII will give a clearer idea than description can of this phenomenon. This occurred only in tests of very tough ductile iron which had been thoroughly worked, and which required several repetitions of the blows to break it in two.

As the deflection caused by each successive blow increased, the transverse crack at the lower part of the test-piece widened, and the surface iron became detached and stood open like a detached bark. A tough, gray ligature with splintered surface connected the two ends, and a finger could be thrust under the skin on either side.

Several photographs were made of instances of this action, it being deemed peculiar to most excellent iron, occurring only with A, C, F, F*x*, and O.

CONTRAST BETWEEN APPEARANCES OF FRACTURES OF IRON WHICH HAVE RECEIVED DIFFERENT AMOUNTS OF WORK.

The illustrations on Plate XIII show the contrasting action of irons P*x* and N, when tested by impact; the first, a choice material thoroughly worked, deflecting greatly and tearing in two; the second, a coarse underworked product, breaking like a pipe-stem by a blow very slight, as compared with that received by iron P*x*, the latter resisting until the fifth 30-foot blow was given, the former yielding with a "square break" at a single 20-foot blow. Tested by tension alone, iron N would have been rated as a most excellent iron. It failed under impact and as a cable. In the second group, same plate, the test-pieces illustrated are those of irons P and F, broken by tension. These irons were rather overworked, and contracted nearly 50 per cent. in area. They were excellent bar iron, but not as valuable for cable as they would have been with less work, the welds not proving reliable.

CRYSTALLIZATION.

The question as to whether crystallization can be produced in iron by stress, or by repetition of stress with alternations of rest, or by vibration, has been very much discussed, and very opposite views are entertained by experts; therefore it was considered that any data which might be gathered during our tests, bearing upon this point, would possess a value.

We have met with but one unmistakable instance of crystallization which was probably produced by alternations of severe stress, sudden strains, recoils, and rest.

The connecting rod of the chain prover was 5″ in diameter, had been in use for forty years, and had, during this period, been frequently subjected to stress up to 250,000 pounds, with recoils produced by rupture of test-pieces.

It was carefully made in the anchor-shop, being hammered from the best quality of wrought-iron scrap; it is not probable that any section of it, if broken when first made, would have displayed crystalline structure, but while we were testing, it parted one day at less than 200,000 pounds stress, and the surface of the fractured ends showed well-defined crystallization, the facets being large and bright as mica; the ends having become injured by rust, the bar was again broken by impact at a point distant over a foot from the first fracture, and the same appearance was found which is shown in the illustration, Plate V, Fig. 1, the original of which is now in the cabinet of the Stevens Institute.

A second case, not so marked, occurred as represented in Fig. 2, same plate, the article being a fractured shackle.

IMPACT TESTS.

The records of tests by impact begin with the history of an examination made upon the contract chain iron in store, made by the chairman of these committees, acting under the instructions of the Navy Department, with the object of ascertaining the character of the iron on hand, and the effect upon such as was found unsuitable for cables, of thorough reworking.

This iron was stowed in piles classified by diameters. Most of it had been received during the war from such contractors as had bid lowest, and its origin beyond this point was unknown; its general character, as found by this examination, was worthless in its present state. The results of the experiments in reworking, and in combining it with scrap iron of superior quality, were such that the iron produced was pronounced by the Chief of the Bureau of Steam-Engineering as "at least equal, if not superior, to the best commercial iron, at less cost."

The department at this date, needing a 2″ cable for a frigate, and being convinced that the stock of chain iron of this size was unreliable, authorized the construction, under the supervision of the chairman of these committees, of the required cable from the condemned material on hand. This was accomplished, and the daily tests of the blooms from which the bars for this cable were rolled is given under the head on "hammered iron."

From these hammered blooms the required 2″ bars were rolled in the copper mill by green hands, and their record is given as that of "iron A." No bar was permitted to enter into this cable which had broken at less than three 30-foot blows. The fag ends and rejected bars were rolled down to smaller sizes and tested as such, there being 348 tests by impact made upon this iron, which are recorded, besides many experiments not recorded or preserved. The remainder of the tests by impact have been made on such bars as we have procured, and had already tested by tension.

When not otherwise specified, the length of each of the pieces tested was equal to twelve times the diameter, these being the usual dimensions of chain cable bolts.

These were scored by a pipe-cutting machine to a depth of $\frac{1}{32}''$, either at the center, or at two points equidistant from the ends and the piece was when tested placed so that the wedge-shaped hammer struck the score.

With nearly all of the contract chain iron, the slight resistance offered by the first score was reduced to but a small percentage of itself when the other scores were struck, hence it is not considered necessary to retain their record, and the results in the table are those procured from the first scores.

EXPLANATION OF SYMBOLS USED IN TABLES

The symbols by which, in the tabulated results, the effect of the blows are described signify as follows:

"V," that a fine, silvery line has become visible on the lower part of the score, indicating an approach to

"S C," a slight crack, in which a needle-point could be inserted, and

"C," a crack wide and deep enough to insert the edge of a knife.

"+," an increase of the opening, but not enough to term

"B C," a bad crack.

"F or T B," a fracture in which the ends are torn apart, leaving long, jagged splinters. (See Plate XIII, Fig. 1. *Px.*)

"$\frac{1}{2}$ F," an incomplete fracture of the same nature, the ends still remaining connected. (See Plates IV, IX, and XII.)

"□," a short, square break, with little or no deflection, the fractured surfaces showing smooth, as though cut in two. (See Plates III, VI, X, and XIII.)

"Closed to hammer," the test-piece is bent to from 110° to 120°, and in contact with the face of the wedge of the hammer. (See Plates IV and XII.)

"Closed down," the piece has been still further closed under the steam hammer, until the sides are in contact the whole length. (See Plates VII, VIII, and XI.)

Record of tests by impact.

CONTRACT CHAIN IRON.

Number of test.	Size of test-piece.	Drop in feet and effect.										Remarks.
		First.		Second.		Third.		Fourth.		Fifth.		
		Drop.	Effect.	Drop.	Effect.	Drop.	Effect.	Drop.	Effect.	Drop.	Effect.	
	″											
1	2¼	10	□	....	....	....	....	....	....	....	....	There were two varieties of iron in the five pieces tested: one coarse and brittle, the breaks of which are marked □; the other a fair, fibrous, tough iron. The former predominated.
2	"	14	□	....	....	....	....	....	....	....	....	
3	"	6	V	8	C	10	F	....	....	....	....	
4	"	10	□	....	....	....	....	....	....	....	....	
5	"	9	....	10	V	11	C	13	+	14	F	
6	2 3/16	6	□	....	....	....	....	....	....	....	....	In addition to the tests recorded upon this size, there were probably a hundred pieces broken at various times, with results no better than those recorded. Among these tests were a number where the bar was struck a number of light blows of from ½ to 1½ foot drop in rapid succession, and although apparently uninjured by any short of the fracture, it was eventually broken square in two by a blow of no greater force. Bars not scored were broken by blows of, in one case, one, in another *two*, and in others *five*, 30-feet drops; in all cases apparently uninjured until the last blow. This lot was selected for experiments in reworking and mixing. The results of thorough rework and mixing with old boiler-iron are shown in the illustrations of fractures by impact, Plate VI, and by tension, Plate I; the specimens photographed being from it.
7	"	4	□	....	....	....	....	....	....	....	....	
8	"	1	V	4	....	6	C	6	□	....	....	
9	"	4	□	....	....	....	....	....	....	....	....	
10	"	6	V	6	□	....	....	....	....	....	....	
11	2⅛	7	....	8	....	9	V	10	C	12	□	A number of bolts tested showed that in the lot there was some fair iron, but the presence of other pieces of coarse, granulous, brittle iron rendered the entire lot unsafe.
12	"	17	....	17	....	17	□	....	....	....	....	
13	"	10	V	11	C	11	+	11	F	....	....	
14	"	14	....	14	V	12	C	12	F	....	....	
15	"	15	....	15	V	15	C	15	F	....	....	
16	2	8	□	....	....	....	....	....	....	....	....	In testing one of the bars, the blow which was withstood by the score struck, broke in two the score several inches from it. This lot of iron was so thoroughly worthless that it was condemned, and to supply its place in the manufacture of a cable needed for the United States frigate Tennessee, the experimental cable was produced, and its record compared with this of the 2″ iron on hand presents a great contrast. Some experiments were made in reworking this lot, and in mixing it with old boiler iron. In one case a bloom was hammered from a pile which consisted of four layers of the 2″ thoroughly reworked and flattened, and three layers of hoop iron on hand. The bloom was swaged into test-pieces 2″ in diameter and 24″ long, and was scored in two places and tested by impact, with the following results, viz: first piece, first score, broke half in two at third 30-foot drop; second score broke entirely in two at fifth blow of 25-foot drop. Another bloom made in the same way, except that some Swedish iron on hand was substituted for the hoop iron, broke readily at light blows.
17	"	8	C	8	□	....	....	....	....	....	....	
18	"	3	□	....	....	....	....	....	....	....	....	
19	"	5	....	4	C	4	□	....	....	....	....	
20	"	5	C	5	□	....	....	....	....	....	....	
21	"	10	□	....	....	....	....	....	....	....	....	
22	"	8	C	7	□	....	....	....	....	....	....	
23	"	10	□	....	....	....	....	....	....	....	....	
24	1 15/16	8	....	8	V	6	C	6	□	....	....	The entire lot was a coarse, granulous, brittle iron, and was condemned.
25	"	7	□	....	....	....	....	....	....	....	....	
26	"	8	C	4	□	....	....	....	....	....	....	
27	"	4	....	4	C	8	+	10	+	10	F	
28	"	6	□	....	....	....	....	....	....	....	....	
29	1⅞	17	□	....	....	....	....	....	....	....	....	This lot was coarse, granulous, and resembled very much an inferior cast iron, being full of seams and air-holes. It was condemned as worthless.
30	"	13	□	....	....	....	....	....	....	....	....	
31	"	10	□	....	....	....	....	....	....	....	....	
32	"	9	□	....	....	....	....	....	....	....	....	
33	"	6	□	....	....	....	....	....	....	....	....	
34	"	8	□	....	....	....	....	....	....	....	....	
35	"	1½	C	1½	□	....	....	....	....	....	....	

PLATE V.

FIG. 1.

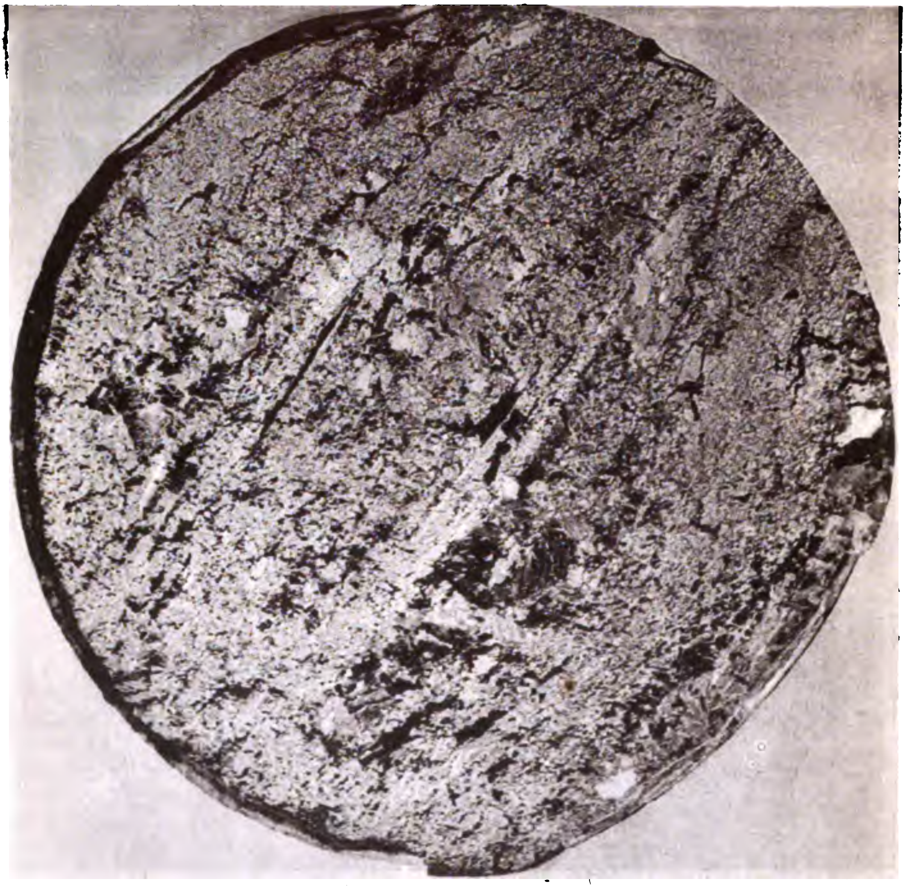
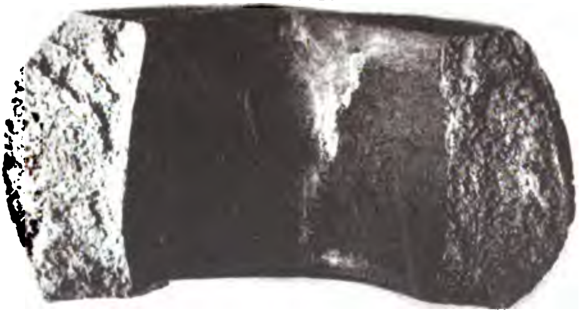


FIG. 2.



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CRYSTALLIZATION.

***Record of tests by impact*—Continued.**

CONTRACT CHAIN IRON—Continued.

Number of test.	Size of test-piece.	Drop, in feet, and effect.										Remarks.
		First.		Second.		Third.		Fourth.		Fifth.		
		Drop.	Effect.	Drop.	Effect.	Drop.	Effect.	Drop.	Effect.	Drop.	Effect.	
36	1 13/16″	6½	☐									The iron was of a fine silvery grain, but was condemned; and this lot furnished the material from which a large portion of the better part of the experimental cable was made. The tensile strength of one piece was 49,000 pounds per square inch. Reworked, its tensile strength was 54,000 pounds. Three cable links made from it broke at 182,000, 172,000, and 158,000 pounds. A single link of this size should not break at less than 230,000 pounds.
37	"	5	☐									
38	"	3½	☐									
39	"	2½		5		6	V	8	☐			
40	"	6	☐									
41	1¾	14	C	14	☐							The entire lot was of poor quality. Tested by tension, one piece showed 51,000 pounds per square inch; tested as cable, three links broke at 137,000, 137,000, and 191,000 pounds. A single link of this size should sustain over 220,000 pounds.
42	"	17	C	12	☐							
43	"	12	☐									
44	"	8	☐									
45	"	5	☐									
46	1 9/16	5	☐									Coarse and granulous; it was so much improved by reworking that it was used largely in the manufacture of the experimental cable. The tensile strength as given by two tests was 58,000 pounds per square inch. As chain links, six were broken as follows, viz: 170,000, 129,000, 125,000, 123,000, 147,000, and 150,000 pounds. Reworked thoroughly, a swaged bar 2″ in diameter stood six blows of 17-feet drop each, and another eight blows of 9-feet drop each.
47	"	3		8	☐							
48	"	4		4	☐							
49	"	4½	C	3	☐							
50	"	4	☐									
51	1 7/16	3	☐									The power of this lot of iron to resist shocks was below our facilities for finding out, a blow of ½-foot drop breaking it as completely as one of 30 feet, the highest delivered. A glass bar of the size could hardly have yielded more readily.
52	"	4	☐									
53	"	½	☐									
54	"	½	☐									
55	"	½	☐									
56	1 5/16	3	☐									There were evidently at least two varieties in the pile, one a fairly tough, well-worked iron, the coarse, granulous.
57	"	2		4	C	4	F					
58	"	4		5	V	5	☐					
59	"	5	☐									
60	"	4	☐									
61	1¼	5		6	C	6	F					Generally of a fair quality, although there were evidently differences in the pile. This lot was not condemned.
62	"	7½	F									
63	"	7½										
64	"	8	F									
65	"	4		4	V	4	+	4	C	3	F	
66	1 3/16	3	☐									Generally bright, granulous; not enough worked.
67	"	2	☐									
68	"	1½	☐									
69	"	1½	C	1½	☐							
70	"	1½		1½	C	1½	F					
71	1⅛	5	☐									Fine, close fiber, and broke generally with a ragged fracture. Its record was fair on many bolts, but there was evidently a mixture of some very brittle iron in the lot.
72	"	4	☐									
73	"	3										
74	"	3	F									
75	"	3½		3	C	3	F					
76	1 1/16	4	☐									This lot was generally coarse, and had received but little work. An occasional piece showed superior qualities, but it was evidently, as a lot, cheap iron.
77	"	4½	☐									
78	"	4	☐									
79	"	4	☐									
80	"	4	☐									
81	1	3		4	C	3	+	3	½F			A fine, fibrous iron. The breaks marked ½F were but half in two, the iron deflecting to the angle of the hammer.
82	"	4	☐									
83	"	4	☐									
84	"	4	V	4	+	4	½F					
85	"	3	☐									

Record of tests by impact.

[Blooms from which bars of iron A (experimental cable) were rolled, and called.]

HAMMERED IRON.

Test-pieces—Bars 24″ long, 2″ in diameter. *Scored*, $\frac{1}{16}$″ deep. Each drop of hammer from height of 30 feet.

Test number.	Number of drop, and effect.					Date of test, and temperature.	Remarks.
	First.	Second.	Third.	Fourth.	Fifth.		
86	V	+	+	C	F	January 22. 35° to 43° F.	Fine close fiber.
87	V	+	C	F	......	....do	Do.
88	V	+	F	......	......	....do	Do.
89	V	+	+	F	......	... do	Fine bright fiber.
90	......	......	......	......	......	....do	Tested by tension.
91	F	......	......	......	......	....do	90 per cent. bright granulous; condemned.
92	C	F	......	......	......	....do	70 per cent. bright granulous; condemned.
93	V	F	......	......	......	....do	
94	V	C	+	F	......	January 23. 28° to 34°.	Bright granulous and gray fiber, 50 per cent. each.
95	V	F	......	......	......	January 25. 31° to 34°.	80 per cent. coarse granulous; condemned.
96	V	F	......	......	......	....do	90 per cent. coarse granulous; condemned.
97	V	F	......	......	......	....do	All dull gray; condemned.
98	V	+	F	......	......	....do	
99	V	+	+	C	F	....do	Long gray fiber.
100	V	C	F	......	......	January 26. 21° to 27°.	
101	V	F	......	......	......	....do	Do.
102	V	F	......	......	......	....do	Interval of 24 hours between blows.
103	V	F	......	......	......	....do	60 per cent. bright granulous; condemned.
104	V	+	C	F	......	....do	60 per cent. gray fiber.
105	V	+	+	F	......	January 27. 21° to 35°.	75 per cent. long fiber.
106	V	+	F	......	......	... do	60 per cent. long fiber.
107	V	+	F	......	......	....do	80 per cent. long fiber.
108	V	F	......	......	......	January 27. 21° to 35°.	90 per cent. bright granulous; condemned.
109	V	F	......	......	......	....do	50 per cent. bright granulous; condemned.
110	V	+	F	......	......	....do	60 per cent. long fiber.
111	V	+	F	......	......	January 28. 34° to 40°.	This lot, except No. 114, seemed to need more work, as they showed bright granulous, short breaks. They were reheated and thoroughly reworked, then retested as per record from 15 to 22.
112	F	......	......	......	......	....do	
113	F	......	......	......	......	....do	
114	V	+	+	C	F	....do	
115	V	+	F	......	......	January 29. 37° F.	
116	V	+	C	+	F	....do	
117	V	+	C	F	......	....do	
118	C	F	......	......	......	... do	Condemned.
119	V	+	C	F	......	....do	
120	C	F	......	......	......	....do	Condemned.
121	C	F	......	......	......	....do	Condemned.
122	S C	+	F	......	......	....do	
123	C	F	......	......	......	....do	Condemned.
124	F	......	......	......	......	January 30. 33° to 39°.	This lot failed utterly, the center showing a bright steel-like surface, the fractures clean with but little fiber. The day's work was reheated, reworked, and again tested (128 to 140) with no improvement. An examination revealed that some patches of boiler-steel that had been put on the old boilers had been largely incorporated with the boiler-iron. Had this lot been subjected to tension tests alone it would have been considered valuable. A bar of it broke at 172,800 pounds, equal to 55,000 pounds to the square inch, and its elastic limit was at nearly 32,000 pounds. The test by impact revealed its worthlessness and it was rejected.
125	F	......	......	......	......	....do	
126	F	......	......	......	......	....do	
127	F	......	......	......	......	....do	
128	F	......	......	......	......	....do	
129	F	......	......	......	......	... do	
130	F	......	......	......	......	....do	
131	F	......	......	......	......	....do	
132	F	......	......	......	......	... do	
133	V	+	C	F	......	....do	
134	F	......	......	......	......	....do	
135	F	......	......	......	......	....do	
136	F	......	......	......	......	....do	
137	F	......	......	......	......	....	
138	V	C	F	......	......	....do	
139	F	......	......	......	......	....do	
140	F	......	......	......	......	....do	

Record of tests by impact—Continued.

HAMMERED IRON—Continued.

Test number.	Number of drop, and effect.					Date of test, and temperature.	Remarks.	
	First.	Second.	Third.	Fourth.	Fifth.			
141	V	C	+	F	......	January 30. 33° to 39° F.	A change in the boiler-iron improved this lot.	
142	V	S C	+	F	......	do	95 per cent. long fiber.	
143	......	......	......	......	......	do	Tested by tension.	
144	V	+	C	F	......	February 2. 80° F.	90 per cent. long fiber	$1\frac{3}{16}$" contract chain-iron and boiler-plate.
145	......	V	+	S C	F	do	do	
146	V	S C	C	+	F	do	do	
147	......	V	+	S C	C	do	do	
148	V	+	S C	C	F	do	do	
149	V	C	F	......	......	February 3. 44° to 54° F.	Long gray fiber	
150	V	+	C	F	......	do	do	
151	V	C	F	......	......	do	do	
152	......	......	......	......	......	do	Tension test	
153	V	+	C	F	......	do	......	
154	V	C	+	F	......	February 4. 25° to 27° F.	Long gray fiber	
155	V	S C	+	F	......	do	do	
156	S C	C	F	......	......	do	do	
157	V	C	F	......	......	do	do	
158	V	S C	C	F	......	do	do	
159	......	......	......	......	......	do	Tension-test	
160	S C	C	+	F	......	February 5. 13° to 21° F.	60 per cent. long fiber	$1\frac{13}{16}$" contract chain-iron and boiler-plate.
161	V	+	F	......	......	do	50 per cent. long fiber	
162	V	S C	F	......	......	do	do	
163	......	......	......	......	......	do	Tension-test	
164	V	S C	C	F	......	do	......	
165	V	S C	F	......	......	do	Long fiber	$1\frac{13}{16}$" contract chain and charcoal bloom gun-bands.
166	V	C	F	......	......	do	do	
167	V	C	F	......	......	do	do	
168	V	C	+	F	......	do	do	
(a)	......	......	......	......	......	February 6. 27° to 34° F.	Tension-test	$1\frac{13}{16}$" contract chain-iron and boiler-plate.
(b)	V	S C	+	F	......	do	Long fiber	
(c)	V	+	C	F	......	do	do	
(d)	V	+	C	½ F	......	do	Broke half in two	
169	V	C	F	......	......	do	Long fiber	
170	V	+	C	F	......	February 8. 9° to 19 F.	Long gray fiber	$1\frac{13}{16}$" contract chain experimental cable-iron and boiler-plate.
171	V	C	+	F	......	do	do	
172	V	C	½ F	......	......	do	do	
173*	V	+	+	C	+	February 9. 8° to 9° F.	Long fiber, broke on sixth blow.	$1\frac{3}{16}$" contract iron and boiler-plate.
174	V	+	C	½ F	......	do	do	
175	V	+	C	+	½ F	do	do	
176	V	+	F	......	......	February 10. 2° to 15° F.	Dark gray fiber	$1\frac{3}{16}$" chain-iron and gun-bands.
177	V	+	F	......	......	do	do	
178	V	+	½ F	......	......	do	do	
179	V	+	F	......	......	do	do	
180	V	+	F	......	......	do	do	
181	......	......	......	......	......	do	Tension-test	
182	V	+	½ F	......	......	February 11. 24° to 32 F.	Long gray fiber	
183*	V	+	S C	+	C	do	Long gray fiber, broke half in two on sixth blow.	
184	S C	+	C	+	F	......	Long gray fiber	
185	V	+	S C	C	F	February 12. 19° to 28° F.	Long fiber	
186	V	+	S C	½ F	......	do	Do.	
187	V	C	F	......	......	do	Do.	
188	V	+	F	......	......	do	Do.	

Record of tests by impact—Continued.

HAMMERED IRON—Continued.

Test number.	Number of drop, and effect.					Date of test, and temperature.	Remarks.	
	First.	Second.	Third.	Fourth.	Fifth.			
189	V	S C	+	F	......	February 15. 23° to 30° F.	Long gray fiber...........	Experimental cable-iron, gun-bands, and boiler-plates, piled in five layers: 1st, three sheets boiler-plate; 2d, gun-bands; 3d, experimental cable-iron; 4th, gun-band, and 5th, four sheets boiler-plate.
190	V	+	S C	½ F	......	....do	......do	
191	V	C	F	......	......	....do	......do	
192	V	+	F	......	......	....do	......do	
193	V	+	C	F	......	....do	......do	
194	V	+	+	F	......	....do	......do	
195	V	+	C	F	......	....do	......do	
196	V	+	C	½ F	......	....do	......do	
197	V	+	+	F	......	....do	Do.	
198	V	+	C	F	......	....do	Do.	
199	V	+	+	C	F	....do	Do.	
200	V	C	F	......	......	....do	Do.	

Test number.	Effect and degrees of deflection at each 30-foot drop.					Date of test, and temperature.	Remarks.	
	First.	Second.	Third.	Fourth.	Fifth.			
	°	°	°	°	°			
201	V. 19	+30	C. 57	B. C.	....	February 15. 10° to 11° F.	From No. 95 to the end of the tests the deflection at each blow was measured and noted.	
202	V. 19	+29	C. 60	F.	....	....do	80 per cent. long gray fiber.	$1\frac{3}{16}$" chain-iron and boiler-plate.
203	V. 17	+26	C. 40	F.	....	....do	90 per cent. long gray fiber.	
204	V. 18	+26	S. C. 39	F.	....	....do	All long gray fiber.	
205	V. 17	S. C. 30	F.	....	....	February 16. 9° to 19° F.	50 per cent. gray fiber.	$1\frac{3}{16}$" contract chain iron and boiler-plate.
206	V. 18	+36	F.	....	....	....do	60 per cent. gray fiber.	
207	S. C. 19	B. C. 53	F.	....	....	....do	All gray fiber.	
208	V. 18	S. C. 30	F.	....	....	February 17. 17° to 26° F.	......do................	$1\frac{3}{16}$" contract chain-iron and boiler-plate.
209	V. 18	S. C. 33	+	F.	....	....do	......do................	
210	V. 18	C. 33	F.	....	....	....do	......do................	
211	V. 18	C. 38	F.	....	....	....do	......do................	
212	V. 25	+33	S. C. 70	F.	....	February 19. 21° to 26° F.	......do................	$1\frac{3}{16}$" contract chain-iron and boiler-plate.
213	V. 27	+38	F.	....	....	....do	......do................	
214	V. 25	+38	F.	....	....	....do	......do................	
215	V. 25	S. C. 33	F.	....	....	....do	......do................	
216	V. 17	+29	C. 44	B. C. 70	F.	February 20. 32° to 33° F.	......do................	$1\frac{1}{16}$" contract chain-iron and boiler-plate.
217	V. 18	+34	C. 45	F.	....	....do	......do................	
218	V. 18	+33	F.	....	....	....do	......do................	
219	F.	....	....	....	....	....do	Condemned	
220	V. 17	+29	S. C. 40	F.	....	February 22. 29° to 45° F.	Gray fiber.............	$1\frac{1}{16}$" contract chain-iron and boiler-plate.
221	V. 23	+29	S. C. 47	F.	....	....do	......do................	
222	V. 17	+26	S. C. 36	F.	....	....do	......do................	
223	V. 19	+40	F.	....	....	February 23. 40° to 53° F.	90 per cent. gray fiber .	$1\frac{5}{16}$" contract chain-iron and boiler-plate.
224	V. 15	+39	S. C. 39	B. C. 49	....	....do	Broke half in two	
225	V. 17	+35	S. C. 44	B. C. 70	F.	....do	All gray fiber	
226	V. 20	+34	C. 49	F.	....	....do	90 per cent. gray fiber..	
227	V. 14	S. C. 29	C. 39	F.	....	....do	Bright center..........	

Record of tests by impact—Continued.

HAMMERED IRON—Continued.

Test number.	Effect and degrees of deflection at each 30-foot drop.					Date of test, and temperature.	Remarks.	
	First.	Second.	Third.	Fourth.	Fifth.			
	°	°	°	°	°			
228	V. 15	+29	S. C. 40	B. C5. 0	F.	February 24. 46° to 54° F.	75 per cent. gray fiber..	1⅛″ chain-iron and boiler-plates.
229	V. 17	C. 29	F.			....do	All gray fiber	
230	V. 17	S. C. 30	C. 57	F.		....do	......do	
231	V. 17	F.				....do	Bright granulous	
232	V. 17	S. C. 29	F.	F.		....do	......do	
233	V. 18	S. C. 35	F.			....do	90 per cent. bright granulous.	
234	V. 17	S. C. 30	C. 45	½ F.		....do	Retest of No. 125 after reworking.	
235	V. 18	+33	S. C. 47	C. 62.	F.	February 25. 53° to 55° F.	Long fiber	1⅛″ chain-iron and boiler-plates.
236	V. 15	+26	S. C. 38	C 60.	F.	....do	......do	
237	V. 17	S. C. 30	B. C. 52	F.		....do	......do	
238*	V. 18	+30	+42	S. C. 53	C 62.	....do	Long fiber; closed under steam-hammer until ends were but 3″ apart, without breaking.	
239	V. 19	+33	+47	S. C. 70	½ F.	February 25. 53° to 55° F.	Long gray fiber	1⅛″ chain-iron and boiler-plates.
240*	V. 20	+33	S. C. 44	+70.	C 93.	....do	......do	
241	V. 17	S. C. 30	C. 47	F.		....do	......do	
242	V. 18	+29	C. S. 45	F.		February 26. 32° to 45° F.	Long gray fiber	1½″ and 1$\frac{3}{16}$″ chain iron and boiler plate.
243	V. 19	S. C. 27	C. 52	F.		....do	......do	
244	V. 18	+30	C. 50	F.		....do	......do	
245	V. 17	S. C. 29	+47	½ F.		....do	......do	
246	V. 18	+33	C. 47	F.		....do	......do	
247	V. 18	+33	S. C. 40	½ F.		....do	......do	
248	V. 17	+29	S. C. 44	½ F.		February 27.† 35° to 43° F.	Gray fiber	The contract chain iron and fag ends of experimental cable iron.
249	V. 17	+33	S. C. 52	½ F.		....do	......do	
250	V. 17	C. 30	F.			....do	......do	
251	V. 17	S. C. 29	C. 42	F.		....do	......do	
252*	V. 18	+29	S. C. 44	C. 55	B. C. 94	March 3. 31° to 29° F.	Closed under steam-hammer.	
253	V. 18	C. 29	½ F.			....do	Long gray fiber	1⅛″ chain iron and boiler plate.
254	V. 17	S. C. 30	C. 57	T. C. 80	F.	....do	......do	
255	V. 17	S. C. 33	+44	C. 55	F.	....do	......do	
256	V. 17	+30	S. C. 40	+85	½ F.	....do	......do	
257*	V. 17	+27	+42	S. C. 50	C 70.	....do	Long gray fiber; stood a 6″ blow unbroken.	
258	V. 19	S. C. 29	C. 40	B. C. 57	F.	....do	Long gray fiber	
259	V. 18	+33	C. 50	½ F.		March 4. 26° to 30° F.	All fibrous	1$\frac{5}{16}$″ chain iron and boiler plate.
260	V. 17	S. C. 29	+44	C. 68	F.	....do	......do	
261	V. 17	S. C. 35	F.			....do	......do	
262	V. 18	+35	C. 49	F.		....do	......do	
263	V. 18	S. C. 35	C. 49	½ F.		March 5. 29° to 31° F.	Long gray fiber	1⅛″ chain iron, boiler plates, and fag ends of experimental cable iron.
264	V. 15	+33	C. 49	F.		....do	......do	
265	V. 18	S. C. 35	F.			....do	......do	
266	V. 17	B. C. 34	F.			....do	......do	
267	V. 17	C. 29	+42	B. C. 57	F.	March 6. 33° to 40° F.	......do	
268	V. 18	C. 34	B. C. 50	+75.	F.	....do	......do	
269	V. 18	C. 34	B. C. 51	F.		....do	......do	
270	S. C. 91	B. C. 42	F.			....do	......do	

† A portion of the blooms hammered this day were rolled down and became the bars from 2″ to 1″ of iron A, the record of which, under tension as bars, is given Nos. 139 to 162, and the comparative strength of bars and links, Nos. 1 to 19.

Record of tests by impact—Continued.

HAMMERED IRON—Continued.

Test number.	Effect and degrees of deflection at each 30-foot drop.					Date of test, and temperature.	Remarks.	
	First.	Second.	Third.	Fourth.	Fifth.			
	°	°	°	°	°			
271	V. 18	+31	C.	½ F.	....	March 8. 33° to 38° F.	Long gray fiber	1⅜" chain iron, boiler plates, and fag ends of experimental cable iron.
272	V. 17	S. C. 33	C.	....	F.	....do	......do..................	
273	V. 19	C. 39	F.	....	....	....do	95 per cent. gray fiber.	
274	S. C. 19	C. 30	F.	....	....	....do	All gray fiber	
275	C. 18	F.	....	....	....	March 9. 32° to 37° F.	30 per cent. fiber	1⅜" chain iron and boiler plates.
276	V. 15	+26	+38	F.	....	... do	90 per cent. fiber	
277	V. 15	C. 27	F.	....	....	....do	40 per cent. fiber	
278	V. 12	C. 23	F.	....	....	....do	80 per cent. granulous.	
279	V. 17	+30	C. 47	F.	....	March 10. 31° to 46° F.	Gray fiber..............	1 3/16" chain iron and boiler plates.
280	V. 17	S. C. 27	F.	....	....	....do	......do..................	
281	V. 15	+30	S. C. 50	F.	....	.. do	..... do	
282	V. 17	+30	F.	....	....	....do	......do..................	
283	V. 17	+27	S C 50	C. 58	F.	March 11. 34° to 48° F.	90 per cent. gray fiber.	1 3/16" chain iron and boiler plate.
284	V. 17	S. C. 29	F.	....	....	....do	Bright center	
285	V. 15	F	....	....	....	....do	80 per cent. bright	
286	V. 17	+27	C. 40	F.	....	....do	All fiber	
287	V. 18	+39	F.	....	....	....do	50 per cent. fiber	
288	F.	....	....	....	....	....do	Condemned	2⅛" chain iron and boiler plate.
289	V. 18	F.	....	....	....	....do	......do......	
290	V. 17	F.	....	....	....	....do	......do..................	
291	V. 17	+33	F.	....	....	March 12. 46° to 63° F.	90 per cent. gray fiber.	1⅜" chain iron and boiler plate.
292	V. 17	+30	F.	....	....	....do	......do..................	
293	....	....	....	....	....	....do	Tension test	
294	S. C. 15	+25	B. C. 47	F.	....	March 15. 47° to 56° F.	Gray fiber..............	1⅜" chain iron and boiler plate.
295	V. 15	+30	B. C. 57	½ F.	....	....do	......do..................	
296	S. C. 17	C. 33	B. C. 60	½ F.	....	....do	......do..................	
297	V. 18	+27	C. 47	+62	½ F.	March 16. 48° to 54° F.	......do..................	Reworked 1⅜" chain iron and boiler plate.
298	V. 17	S. C. 33	C. 52	F.	....	....do	......do..................	
299	V. 18	S. C 33	+47	C. 75	½ F.	....do	......do..................	
300	V. 15	+33	C. 57	F.	....	March 17. 38° to 35° F.	90 per cent. gray fiber.	Reworked 1⅜" chain iron and boiler plate.
301	V. 15	+30	C. 50	F.	....	....do	All gray fiber	
302	V. 17	+30	½ F.	....	....	....do	End hanging	
303	V. 17	S. C. 35	+44	F.	....	....do	90 per cent. gray fiber.	
304	V, 15	+29	C. 45	F.	....	....do	......do..................	

NOTE.—The temperatures were not observed at the time of making the tests; the addition has been since made from data supplied by the Signal Service Office, and the temperatures given are those at 7.35 a. m. and noon of the several days. The tests were generally made at about 10 a. m., the iron having remained at least twenty-four hours in the shop, where the temperature during the day was probably 30° above that of the outer air, and at night probably 10° above. This note covers all of the temperature records when not otherwise specified. Test-pieces marked * withstood a *sixth* 30-foot blow without breaking completely in two, and were subsequently closed under steam-hammer until ends were but 8" asunder, only two breaking by this test.

Record of tests by impact—Continued.

IRON A.

[Test-pieces 24″ long, 2″ diameter. Scored 1/16″.]

Test number.	Effect and degrees of deflection at each 30-foot drop.					Date of test, and temperature.	Remarks.
	First.	Second.	Third.	Fourth.	Fifth.		
	°	°	°	°	°	1875.	
305	V. 30	+48	□			January 29. 34° to 40° F.	
306	V. 29	+48	□			do	
307	V. 30	+46	+59	□		do	
308*	□					January 30. 33° to 39° F.	Condemned.
309						do	Tension test.
310	V. 30	T. B. 90				do	Condemned.
311	V. 28	+46	T. B. 82			do	A link made from this bar broke at 283,000 pounds.
312	V. 30	T. B. 92				do	Condemned.
313	V. 29	+48	□			do	
314	V. 27	+43	+59	C. 73	T. B. 94	do	
315	V. 28	+45	+60	F.		do	
316	V. 28	+47	C. 59	□		do	
317	20	V. 46	+50	C. 76	T. B. 98	do	
318	V. 29	+43	C. 68	+78	T. B. 96	February 1. 20° to 26° F.	
319	V. 28	+47	S. C. 60	+76	F.	do	Both from bar, made of same bloom.
320	V. 32	F.				do	They were condemned and rerolled to 1⅞″.
321	V. 32	F.				do	60 per cent. bright.
322	V. 30	+51	F.			do	95 per cent. bright; condemned.
323*	C. 40	F.				do	Both from same bar; 90 per cent. bright.
324*	F.					do	They were condemned and reworked.
325*	F.					do	40 per cent. fibrous.
326	V. 30.	+48	S. C. 64	F.		do	Made into cylinders.
327						do	
328						do	
329	V. 28	C. 40	F.			do	
330	36	V. 51	+69	F.		do	Condemned bars 323 to 325; rerolled to 1⅞″ and drop reduced to 20 feet.
331	V. 38	F.				do	
332	V. 26	+45	F.			do	
333	V. 29	46. F.				February 2. 30° F.	Long gray fiber.
334	V. 26	C.	F.			do	Do.
335	F.					do	Both from the same bar, and were condemned and rerolled to 1⅞″.
336	F.					do	
337	V. 24	C. 46	F.			do	95 per cent. gray fiber.
338	V. 26	F.				do	
339	V. 26	+50	F.			do	Condemned bars 355 and 356 rerolled to 1⅞″.
340	C. 30	F.				do	
341	C. 32	F.				do	
342*	F.					February 6. 27° to 34° F.	Fine bright granulous; condemned.
343*	F.					do	Do.
344	V. 26	+44	S. C. 58	F.		do	
345	V. 24	+49	F.			do	
346*	F.					do	Fine bright granulous; condemned.
347	V. 25	+46	C. 61	F.		do	This lot, from Nos. 342 to 352 inclusive, was in many cases overheated and showed fire cracks. The condemned bars were remade, rerolled, and again tested as recorded at 354 and 355.
348	V. 23	+48	+61	C. 73	F.	do	
349	V. 26	+47	F.			do	
350	V. 26	+40	F.			do	
351	V. 26	+47	F.			do	
352*	F.					do	Condemned.
353	V. 24	+42	F.			do	
354	V.	+	F.			do	Condemned; made from Nos. 342, 343, 346, and 352.
355	V.	+	+	+	F.		Passed.
356	V. 20	+40	F.			February 8. 9° to 19° F.	75 per cent. fiber.
357	V. 24	+44	F.			do	All fiber.
358	V. 25	+42	F.			do	60 per cent. fiber.
359	V. 26	+40	+71	½ F.		do	All fiber.
360	V. 25	+48	F.			do	50 per cent. fiber.
361	V. 25	+45	+71	F.		do	95 per cent. fiber.
362						do	Unscored; it was struck twelve 30-foot blows and then closed under the steam-hammer without a crack.

Record of tests by impact—Continued.

IRON A—Continued.

Test number.	Effect and degrees of deflection at each 30-foot drop.					Date of test, and temperature.	Remarks.
	First.	Second.	Third.	Fourth.	Fifth.		
	°	°	°	°	°	1875.	
363	V. 26	+44	• F			February 12. 19° to 28° F.	The whole of this day's work condemned and rerolled to 1¼". All showed long fibrous fractures, but required more work.
364	V. 28	F.				do	
365	V. 30	F.				do	
366	F.					do	
367	V. 26	C. 40	F			February 17. 17° to 36° F.	Nos. 367 and 370 were further tested by rolling down fag-ends to 1⅜" diameter and struck as per record of Nos. 371 and 372.
368	V. 24	+42½	S. C. 61	C. 76	F.	do	
369	V. 23	+44	S. C. 6	F.		do	
370	V. 26	+47	F			do	
371	V.	F				do	No. 367 rerolled to 1⅜".
372	V.	+	F.			do	No. 370 rerolled to 1⅜".
373	V. 34	+50	+57	C. 65	F.	February 19. 17° to 36° F.	Long gray fiber; weight increased to 150 pounds.
374	V. 33	C. 47	F.			do	Do.
375	V. 24	+33	F.			February 27. 35° to 43° F.	
376	V. 20	+36	+	C.	F.	do	All good long gray fiber.
377	C. 24	+40	F			do	
378	V. 22	+33	+	F.		do	
379	V. 18	+36	+	+	F.	do	
380	V. 24	+40	+56	F.		March 17. 30° to 35° F.	All good long gray fiber.
381	V. 24	+41	+56	F.		do	
382	V. 26	+44	+53	F.		March 20, 32° to 35° F.	
383	V. 25	+41	+54	C. 63	F.	do	
384	V. 25	+42	+54	C. 63	F.	March 26, 35° to 44° F.	

Record of tests by impact of fag-ends of 2-inch bars, rolled down to 1¼ inch and scored $\frac{1}{32}$".

IRON A.

Number of test.	Effect and deflection of first blow.	Remarks.	Number of test.	Effect and deflection of first blow.	Remarks.
385	□.	Slightly fire-cracked.	404	□.	Short, bright steely.
386	V.	Good.	405	S. C.	Gray fiber.
387	V.	Do.	406	V.	Slight fire-cracks.
388		Do.	407	V.	Gray fiber.
389	S. C.	Slight fire-cracks.	408	S. C.	Do.
390	S. C.	Do.	409	□.	50 per cent. bright.
391	C.	Very good.	410	V.	Very good.
392	C.		411	B. C.	All gray.
393	C.	Very slight fire-cracks.	412	□.	90 per cent. bright.
394	F.	90 per cent. gray.	413	F.	98 per cent. gray.
395	V.		414	V.	Good.
396	V.	Slight fire-cracks.	415	S. C.	Do.
397		Half in two; gray fiber.	416	S. C.	Slight fire-cracks.
398	□.	Fine, steely.	417	□.	Fine, steely.
399	V.	Good.	418	V.	Gray fiber; good.
400	S. C.	Do.	419	V.	Do.
401	S. C.	Do.	420	B. C.	Do.
402	S. C.	Do.	421	C.	Do.
403	S. C.	Do.	422	C.	Do.

Record of tests by impact of fag-ends of 2-inch bars, &c.—Continued.

IRON A—Continued.

Number of test.	Effect and deflection of first blow.	Remarks.	Number of test.	Effect and deflection of first blow.	Remarks.
423	C.	Gray fiber; good.	446	V.	Slight fire-cracks.
424	C.	95 per cent. dull gray.	447	F.	End hanging.
425	□	Steely.	448	B. C.	Gray fiber.
426	T. B.	Long fiber.	449	B. C.	Gray fiber; end hanging.
427	T. B.	Do.	450	S. C.	Long fiber.
428	□	Rejected; steely.	451	F.	Half in two; long fiber.
429	S. C.	All fiber.	452	□	98 per cent. gray fiber; short.
430	□	Fine, steely; rejected.	453	C.	90 per cent. gray fiber; short.
431	B. C.	End hanging.	454	□	All gray fiber; short.
432	B. C.	Screw.	455	V.	Long fiber.
433	□	Fine, steely.	456	□	Fine, bright steely.
434	V.	Slight fire-cracks.	457	115°	Thread chased on it; bent double.
435	S. C.	Fire-cracked slightly.	458	□	Fine, steely.
436	B. C.	All gray fiber.	459	□	Short gray fiber.
437	B. C.	Do.	460	V.	Fire-cracked.
438	□	50 per cent. bright.	461	V.	
439	□	All gray; very dark.	462	V.	
440	C.	All gray; good piece.	463	F.	End hanging.
441	C.	All gray.	464	B. C.	Long fiber.
442	S. C.	Do.	465	S. C.	
443	......	Half in two; long fiber.	466	V.	Slight fire-cracks.
444	□	Dull gray; rejected.	467	V.	
445	□	50 per cent. bright.			

All of these tests made February 16, 1875.

Temperature, 9.5°, 19.5°, and 24° at 7.35 a. m., noon, and 4.35 p. m.

Nos. 431 and 455 were, before being tested, made into screws, 16 threads to the inch; see Plate VIII, Fig. 1.

Record of tests by impact.

IRON B.

Number of test.	Diameter of bar.	Drop of hammer in feet, effect, and degrees of deflection produced at each blow.										Remarks.	
		First.		Second.		Third.		Fourth.		Fifth.			
		Drop.	Effect and deflection.	Drop.	Effect and deflection.	Drop.	Effect and deflection.	Drop.	Effect and deflection.	Drop.	Effect and deflection.		
	″		°		°		°		°		°		
468	$1\frac{7}{16}$	13	13	13	S. C. 29	7	C. 58	13	□	....	....	Mixed fiber, and granulous; all three from same bar.	
469	......	13	V. 19	13	C. 34	13	□	....	....	....	....		
470	......	13	C. 24	13	□	....	....	....	....	....	....		
471	$1\frac{7}{16}$	10	□	....	....	....	....	....	....	....	....	Coarse granulous; all three from same bar.	
472	......	13	□	....	....	....	....	....	....	....	....		
473	......	10	□	....	....	....	....	....	....	....	....		
474	$1\frac{7}{16}$	13	....	....	....	....	....	....	....	....	....	Granulous.	Both from same bar.
475	......	9	10	9	V. 21	9	C. 54	10	F. 115	....	....	Granulous and fiber.	
476	$1\frac{7}{16}$	12	19	12	S. C. 35	13	C. 56	13	+ 85	14	F. 115	Fiber.	All from same bar.
477	......	13	□	....	....	....	....	....	....	....	....	Granulous and fiber.	
478	......	13	C. 34	13	F. 118	....	....	....	....	....	....	Do.	

The broken pieces were thoroughly reworked by the hammer, swaged into 1½″ bars and annealed; then scored and retested as follows: First piece, first score, cracked at first 10-foot blow, broke half in two at second; second score, cracked at first 10-foot blow, broke half in two at second. Second piece, first score, broke half in two on third 10-foot blow; second score, broke half in two on fourth 10-foot blow; and the iron was considered to be improved by the work.

Record of tests by impact—Continued.

IRON C—CHAIN LINKS DELIVERED.

Number of test.	Diameter of bar.	Drop of hammer in feet, effect, and deflection produced at each blow.										Remarks.
		First.		Second.		Third.		Fourth.		Fifth.		
		Drop.	Effect and deflection.	Drop.	Effect and deflection.	Drop.	Effect and deflection.	Drop.	Effect and deflection.	Drop.	Effect and deflection.	
479	″ 1⅜	17	V.	17	C.	17	F.	....	......	....	......	Irregular break; dark fiber, and coarse granulous.
480	"	24	V.	17	+	17	C.	17	F.	....	......	Tearing break; dark open fiber.
481	"	30	C.	30	+	10	+	10	+	....	......	At 2d blow showed a peeling off of skin (barking).*
482	"	30	C.	30	+	30	+	....	......	....	......	Skin or outside peeled off; heart sound (barking).
483	"	13	C.	10	+	8	□	....	......	....	......	Coarse, bright granulous.
484	"	15	V.	15	+	12	+	10	8	....	......	Outside slabbed off.
485	"	17	V.	17	C.	17	F.	....	......	....	......	Mixed granulous and fibrous.
486	"	20	□	....	......	....	......	....	......	....	......	Coarse granulous.
487	"	15	V.	15	C.	15	□	....	......	....	......	Fine granulous mixed with dark fiber.
488	"	17	□	....	......	....	......	....	......	....	......	Bright granulous.
489	1⅝	17	V.	17	C.	17	F.	....	......	....	......	Fine granulous.
490	"	20	□	....	......	....	......	...	......	....	......	Do.
491	"	15	□	....	......	....	......	....	......	....	......	Bright granulous.
492	1⅛	18	□	....	......	....	......	....	......	....	......	Bright granulous and dark fiber.
493	"	14	F.	....	......	....	......	....	......	....	......	Do.
494	"	12	F.	....	......	....	......	...	......	....	......	Do.
495	"	11	F.	....	......	....	......	....	......	....	......	
496	"	16	F.	....	......	....	......	....	......	....	......	
497	"	12	C.	13	F.	....	......	....	......	....	......	
498	"	12	F.	....	......	....	......	....	......	....	......	
499	"	12	C.	12	+	12	F.	....	......	....	......	
500	"	18	□	....	......	....	......	....	......	....	......	
501	"	11	V.	11	C.	12	+	13	+	13	+	13 + 15 + 15, half in two.†

* See Plate XII, Fig. 1. † See Plate IX, Fig. 1.

Record of tests by impact—Continued.

IRON C—BARS SENT AS SAMPLES.

Number of test.	Diameter of bar.	Drop of hammer in feet, effect, and degrees of deflection produced at each blow.								Remarks.
		First.		Second.		Third.		Fourth.		
		Drop.	Effect and deflection.	Drop.	Effect and deflection.	Drop.	Effect and deflection.	Drop.	Effect and deflection.	
	"		°		°		°		°	
502	2	30	C.	30	□	....	....	....	....	Bright granulous.
503	1⅞	25	□	....	....	....	....	....	....	Very dark, with large bright granulous spots.
504	1¾	20	□	....	....	....	....	....	....	Dark fiber.
505	"	15	□	....	....	....	....	....	....	Very dark, with large bright granulous spots.
506	1⅝	10	C. 26	7	+37	6	F.	....	....	Dark fiber.
507	"	8	F.	....	....	....	....	....	....	Bright, coarse granulous.
508	1½	10	C. 36	5	□	....	....	....	....	Very dark, with bright granulous spots.
509	"	12	C. 20	12	+48	12	+86	18	T. F.	Tearing break; bright fiber.
510	"	13	½ F. 115	....	....	....	....	....	....	Broken half in two.
511	"	20	□	....	....	....	....	....	....	Bright granulous.
512	"	15	□	....	....	....	....	....	....	Do.
513	"	12	C, 58	12	T. F.	....	....	....	....	Tearing break; fibrous iron.
514	"	6	V. 15	6	□	....	....	....	....	95 per cent. bright granulous. Temperature, 43° F.
515	"	8	F	....	....	....	....	....	....	All bright granulous.
516	1¼	6	S. C. 37	8	C. 62	5	T. F.	....	....	End hanging; gray fiber.
517	"	12	S. C. 34	8	T. F.	....	....	....	....	Do.
518	"	10	S. C. 30	10	C. 47	10	+60	9	F.	Dark fiber.
					Unscored.					
519	1¹¹⁄₁₆	30	30	30	60	30	85	30	110	Closed under steam-hammer; no injury.
520	1½	30	40	30	82	30	115	....	....	Closed under steam-hammer; cracked inside.
521	1¼	30	76	30	115	....	....	....	....	Closed under steam-hammer; slight crack inside.

IRON D—SECOND LOT.

Number of test.	Diameter.	Drop of hammer in feet, effect, and degrees of deflection produced at each blow.										Remarks.
		First.		Second.		Third.		Fourth.		Fifth.		
		Drop.	Effect and deflection.	Drop.	Effect and deflection.	Drop.	Effect and deflection.	Drop.	Effect and deflection.	Drop.	Effect and deflection.	
	"		°		°		°		°		°	
522	2	20	□	....	....	....	....	....	....	....	....	All bright, coarse granulous.
523	1⅞	10	S. C. 18	8	T. B. 110	....	....	....	....	....	....	End hanging.
524	1¾	20	S. C. 20	8	F.	....	....	....	....	....	....	All bright, granulous.
525	1⅝	20	S. C. 19	8	+24	5	B. C. 35	5	+68	5	T. B. 115	10 per cent. bright; end hanging.
526	1½	20	V. 10	10	□	....	....	....	....	....	....	Fine bright granulous.
527	1⅜	10	□	....	....	....	....	....	....	....	....	Do.
528	1¼	8	S. C. 24	8	C. 65	5	F.	....	....	....	....	50 per cent. bright granulous.
529	1⅛	8	C. 38	5	□	....	....	....	....	....	....	Do.
530	1	8	□	....	....	....	....	....	....	....	....	80 per cent. bright granulous.

Record of tests by impact—Continued.

IRON D (SECOND LOT)—Continued.

This lot having been tested on a very cold day, the temperature during the night being below 30° F. and the bars resting at the foot of the impact hammer all night, in probably not over 40° temperature, they were thoroughly chilled when tested, and the experiment was repeated, as follows, upon bars which had been kept in a temperature of about 60° for twenty-four hours previous to testing, with no appreciable difference in results.

Number of test.	Diameter.	Drop of hammer in feet, effect, and degrees of deflection produced at each blow.										Remarks.
		First.		Second.		Third.		Fourth.		Fifth.		
		Drop.	Effect and deflection.	Drop.	Effect and deflection.	Drop.	Effect and deflection.	Drop.	Effect and deflection.	Drop.	Effect and deflection.	
	"		°		°		°		°		°	
531	2	30	□	....	....	....	....	....	....	....	....	
532	1⅞	30	□	....	....	....	....	....	....	....	....	
533	1¾	30	S. C. 27	30	C. 45	30	B. C. 65	30	+109	....	....	
534	1⅝	30	C. 50	30	B. C. 80	30	T. 111	....	....	....	....	
535	1½	30	S. C. 53	30	+84	30	□	....	....	....	....	
536	1⅜	20	□	....	....	....	....	....	....	....	....	
537	1¼	15	□	....	....	....	....	....	....	....	....	
538	1⅛	10	B. C. 80	10	T. 115	....	....	....	....	....	....	
539	1	12	□	....	....	....	....	....	....	....	....	

Number of test.	Diameter.	Drop of hammer in feet, effect, and degrees of deflection produced by each blow.										Remarks.
		First.		Second.		Third.		Fourth.		Fifth.		
		Drop.	Effect and deflection.	Drop.	Effect and deflection.	Drop.	Effect and deflection.	Drop.	Effect and deflection.	Drop.	Effect and deflection.	
		Scored.										
	"		°		°		°		°		°	
540	2	30	□	....	....	....	....	....	....	....	....	Coarse and bright.
541	1⅞	30	□	....	....	....	....	....	....	....	....	Do.
542	1¾	30	S. C. 27	30	C. 45	30	B. C. 65	30	+109	....	....	Gray fiber.
543	1⅝	30	C. 50	30	B. C. 80	30	T. 111	....	....	....	....	Gray fiber; end hanging.
544	1½	30	S. C. 53	30	+84	30	□	....	....	....	....	Fine bright granulous.
545	1⅜	20	□	....	....	....	....	....	....	....	....	Do.
546	1¼	15	□	....	....	....	....	....	....	....	....	Do.
547	1⅛	10	B. C. 80	10	T. 115	....	....	....	....	....	....	50 per cent. gray; the rest fine bright.
548	1	12	□	....	....	....	....	....	....	....	....	All fine bright granulous.

IRON E.

549	2	30	F. 115	....	....	....	....	....	....	....	....	Fibrous.
550	"	26	□	....	....	....	....	....	....	....	....	Square break; granulous and fibrous.
551	"	22	□	....	....	....	....	....	....	....	....	80 per cent. granulous.
552	"	17	□	....	....	....	....	....	....	....	....	Do.
553	1⅞	26	□	....	....	....	....	....	....	....	....	Do.
554	1¾	17	20	17	V. 29	17	+41	17	+58	17	C. 90	Torn in two at the sixth blow.
555	1⅝	17	□	....	....	....	....	....	....	....	....	Bright granulous with a little fiber.
556	"	12	□	....	....	....	....	....	....	....	....	Do.
557	1⅜	20	C	20	F.	....	....	....	....	....	....	Dark fiber.
558	1¼	20	□	....	....	....	....	....	....	....	....	
559	"	12	F.	....	....	....	....	....	....	....	....	End hanging; 90 per cent. gray fiber.
560	"	11	T. B. 103	....	....	....	....	....	....	....	....	Do.
561	"	10	B. C. 109	8	F.	....	....	....	....	....	....	
562	"	6	C. 30	6	+70	5	F.	....	....	....	....	End hanging.
563	"	12	F.	....	....	....	....	....	....	....	....	90 per cent. gray fiber; end hanging on.

Record of tests by impact—Continued.

IRON F.

Number of test.	Diameter.	Drop of hammer in feet, effect, and degrees of deflection produced by each blow.										Remarks.
		First.		Second.		Third.		Fourth.		Fifth.		
		Drop.	Effect and deflection.	Drop.	Effect and deflection.	Drop.	Effect and deflection.	Drop.	Effect and deflection.	Drop.	Effect and deflection.	
		Scored.										
	″		°		°		°		°		°	
564	2	30	S. C. 18	30	T. C. 31	30	+45	30	+62	30	+90	Closed to face of hammer by a sixth blow.
565	1⅞	30	C. 23	30	½ F.	....	....	....	......	....	......	Gray fiber; end hanging.*
566	1¾	30	C. 39	30	½ F.	....	....	....	......	....	......	Gray fiber; broken in two.*
567	1⅝	30	F.	....	....	....	....	....	......	....	......	Do.*
568	1½	25	C. 27	20	B. C. 55	20	½ F.	....	......	....	......	Do.*
569	1⅜	25	90 F.	....	....	....	....	....	......	....	......	Do.*
570	1¼	22	F.	....	....	....	....	....	......	....	......	Do.*
571	1⅛	18	F.	....	....	....	....	....	......	....	......	Do.*
572	1	10	F.	....	....	....	....	....	......	....	......	Do.*

IRON *Fx*—NO. 1.

Number of test.	Diameter.	Number of 30-foot drop; effect, and degrees of deflection at each drop.						Remarks.
		First.	Second.	Third.	Fourth.	Fifth.	Sixth.	
		Effect and deflection.	Effect and deflection.	Effect and deflection.	Effect and deflection.	Effect and deflection.	Effect and deflection.	
	″	°	°	°	°	°	°	
573	2	S. C. 37	C. 50	+63	T. C. 67	F.	....	Slabbed up and closed to hammer.
574	1⅞	S. C. 40	C. 75	T. C. 95	107½ F.	....	....	Closed to face of impact-hammer.
575	1¾	S. C. 45	C. 70	T. C. 110	T. B.	....	....	Broke in two.
576	1⅝	C. 85	+100	½ F.	....	....	....	End hanging on.
577	1½	C. 65	T. B.	....	....	....	....	
578	1⅜	T. C. 75	110½ F.	....	....	....	....	Closed to face of impact-hammer.
579	1¼	T. C. 90	112½ F.	....	....	....	....	Do.
580	1⅛	110½ F.	....	....	....	....	....	Do.
581	1	110½ F.	....	....	....	....	....	Do.

IRON *Fx*—NO. 3.

		°	°	°	°	°		
582	2	V. 20	C. 40	T. C. 60	+80	+100	½ F.	Except the 1⅞″ all of the pieces broke with long, tearing fracttures, the ends hanging on in several cases.
583	1⅞	V. 25	□	....	....	....	....	
584	1¾	V. 30	T. C. 60	+90	T. B. 115	....	....	
585	1⅝	S. C. 40	T. C. 70	T. B. 117	....	....	....	
586	1½	S. C. 48	T. C. 76	T. B. 116	....	....	....	
587	1⅜	C. 70	T. B. 112	....	....	....	....	
588	1¼	C. 80	T. B. 117	....	....	....	....	
589	1⅛	F.	....	....	....	....	....	
590	1	F.	....	....	....	....	....	

*Showed long fibrous structure.

***Record of tests by impact*—Continued.**

IRON K.

Number of test.	Diameter.	Drop of hammer in feet; effect and deflection produced at each blow.									
		First.		Second.		Third.		Fourth.		Fifth.	
		Drop.	Effect and deflection.	Drop.	Effect and deflection.	Drop.	Effect and deflection.	Drop.	Effect and deflection.	Drop.	Effect and deflection.
	"										
591	2	30	V.	30	+	30	C.	30	F.	....	....
592	"	30	V.	30	+	30	S. C.	30	+	30	F.
593	"	30	□	....	....	....	....	....	....	....	....
594	"	30	□	....	....	....	....	....	....	....	....
595	"	20	□	....	....	....	....	....	....	....	....
596	"	10	B. C.	....	....	....	....	....	....	....	....
597	1¾	15	□	....	....	....	....	....	....	....	....
598	"	10	□	....	....	....	....	....	....	....	....
599	"	8	C. 36	8	□	....	....	....	....	....	....
600	1$\frac{11}{16}$	12	....	12	□	....	....	....	....	....	....
601	1⅝	8	□	....	....	....	....	....	....	....	....
602	1½	6	□	....	....	....	....	....	....	....	....
603	"	4	□	....	....	....	....	....	....	....	....
		Unscored.									
604	1¾	30	25	30	57	30	72	30	86	30	115
605	1⅝	30	38	30	64	30	90	30	105	....	....
606	1½	30	42	30	83	30	116	....	....	....	....

Tests 1 and 2 were made upon a bar rolled by the manufacturer, from a pile in which flats of charcoal-bloom were placed in center and outside of flats of ordinary crude iron K; flats of the latter were sent to us, and, being combined with old boiler iron, were hammered into 2" bars, the records of which under impact are Nos. 1, 2, and 3, page 215. Nos. 1 and 2 showed long gray fiber; the remainder of this lot showed fine, bright, steely fractures.

All of the unscored pieces closed down under the steam-hammer without injury.

HAMMERED IRON MADE OF IRON K, MIXED WITH BOILER-IRON.

Number of test.	Diameter.	Number of 30-foot drops of hammer; effect and deflection produced at each drop.									Remarks.
		First.	Second.	Third.	Fourth.	Fifth.	Sixth.	Seventh.	Eighth.	Ninth.	
607	2"	......	V.	C.	F.	......	......	......	....	....	These three pieces were made from the crude flats of the 2" iron K mixed with boiler-iron and reworked.
608	"	......	V.	C.	+	B. C.	½ F.	......	....	....	
609	"	......	V.	S. C.	C.	+	+	B. C.	+	F.	
610	"	......	V.	S. C.	C.	+	B. C.	F.	....	....	Made from fragments of iron K mixed with boiler-iron and reworked.
611	1¾	V.	S. C.	C.	+	F.	......	......	....	....	
612	2	V.	S. C.	C.	+	F.	......	......	....	....	Made from 1$\frac{11}{16}$" iron K mixed with boiler-iron and reworked. All showed fine gray fiber.
613	"	S. C.	C.	+	F.	......	......	......	....	....	
614	"	V.	S. C.	C.	+	+	F.	......	....	....	
615	"	□	......	......	....	......	......	......	....	....	Made from 2" iron K reworked without mixing with boiler-iron.
616	"	□	......	......	....	......	......	......	....	....	
617	"	□	......	......	....	......	......	......	....	....	Do.
618	"	B. C.	F.	......	....	......	......	......	....	....	Do.

One unscored 2" bar, made from 2" iron K mixed with boiler-iron, received twelve 30-foot blows, and was then closed down under the steam-hammer without injury. The failure of the bars which were simply "reworked" demonstrates that the iron had received originally all the work which could benefit it.

Record of tests by impact—Continued.

IRON M.

Number of test.	Diameter.	Drop in feet, effect, and of deflection produced at each blow.								Remarks.
		First.		Second.		Third.		Fourth.		
		Drop.	Effect and deflection.	Drop.	Effect and deflection.	Drop.	Effect and deflection.	Drop.	Effect and deflection.	
	″		°	°	°	°	°	°	°	
619	2¼	30	□	....	....	....	....	....	....	All bright granulous.
620	"	25	□	....	....	....	....	....	....	Do.
621	2	25	□	....	....	....	....	....	....	Do.
622	"	20	C.	5	□	....	....	....	....	Do.
623	1⅞	20	C.	10	□	....	....	....	....	90 per cent. bright granulous.
624	"	22	F.	....	....	....	....	....	....	90 per cent. bright granulous.
625	1¾	20	□	....	....	....	....	....	....	80 per cent. bright granulous.
626	"	15	C.	5	□	....	....	....	....	
627	1⅝	15	C.	8	F.	....	....	....	....	Do.
628	"	16	□	....	....	....	....	....	....	
629	1½	17	□	....	....	....	....	....	....	Dark, short fiber and bright granulous.
630	"	10	C.	10	+	6	F.	....	....	
631	1⅜	12	□	....	....	....	....	....	....	Bright granulous; very short.
632	"	10	□	....	....	....	....	....	....	90 per cent. bright granulous.
633	"	8	□	....	....	....	....	....	....	Bright granulous; very short.
634	"	6	F.	....	....	....	....	....	....	
635	"	5	C.	3	F.	....	....	....	....	90 per cent. bright.
636	"	4	C.	4	+	4	F.	....	....	Do.
637	"	6	□	....	....	....	....	....	....	Dull fiber and bright granulous.
638	"	5	T.	....	....	....	....	....	....	90 per cent. bright granulous.

IRON N.

639	2	25	C. 30	5	□	....	....	....	....	80 per cent. bright, coarse granulous.
640	1⅞	20	□	....	....	....	....	....	....	95 per cent. bright, coarse granulous.
641	1¾	25	□	....	....	....	....	....	....	80 per cent. bright granulous.
642	1⅝	25	C. 40	10	T. B.	..	....	....	....	90 per cent. bright granulous.
643	1½	15	V. 20	15	C. 40	12	□	....	....	50 per cent. gray fiber.
644	1⅜	10	V. 25	10	S. C. 50	10	C. 60	8	T. B.	80 per cent. gray fiber.
645	1¼	8	V. 30	6	□	....	....	....	....	50 per cent. gray fiber.
646	1⅛	0	V. 32	6	□	....	....	....	....	Do.

IRON O.

647	2	30	□	....	....	....	....	....	....	
648	1⅞	30	V. 25	30	S. C. 45	30	T. C. 64	30	+ 85	Not broken at fifth blow.
649	1¾	30	C. 40	30	T. C. 71	30	+ 100	10	T. B. 115	
650	1⅝	30	C. 45	30	T. C. 86	30	T. B. 115	....	....	
651	"	30	T. C. 45	30	+ 90	30	T. B. 115	....	....	
652	1⅜	30	T. C. 60	30	T. B. 110	..	....	....	....	
653	1¼	30	T. C. 82	15	T. B. 105	....	....	....	....	
654	1⅛	27	T. B. 98	...	....	....	....	....	....	
655	"	20	T. C. 65	10	+ 95	....	....	....	....	
656	1	18	T. B. 95	....	....	....	....	....	....	
657	"	8	C. 55	8	T. C. 95	....	....	....	....	

All the breaks of iron O, except the 2″, show a bright, clear fiber, the outside or skin to the depth of the score split or slabbed off, similar to the bark from a piece of wood. (See Plate XII.) The pieces below 1⅝″ diameter were closed under the steam-hammer without breaking them off. The 1⅝″ and 1⅞″ broke in two when struck by steam-hammer after the ends had met.

Record of tests by impact—Continued.

IRON P.

Number of test.	Diameter of bar.	Drop of hammer in feet, effect, and degrees of deflection produced at each blow.												Remarks.
		First.		Second.		Third.		Fourth.		Fifth.		Sixth.		
		Drop.	Effect and deflection.	Drop.	Effect and deflection.	Drop.	Effect and deflection.	Drop.	Effect and deflection.	Drop.	Effect and deflection.	Drop.	Effect and deflection.	
		Scored.												
658	1⅜"		°		°		°		°		°		°	
659	1⅝	12	F.	....	....	....	......	....	....	....	......	....	......	Lot Jan., 1877.
660	"	13	□	....	....	....	......	....	....	....	......	....	......	Fine, bright, steely.
		12	½ F.	....	....	....	......	....	....	....	......	....	......	50 p. c. steely; 50 p. c. fiber.
661	"	12	½ F.	....	....	....	......	....	....	....	......	....	......	End hanging; 50 p. c. bright.
662	"	9	C.	4	□	....	......	....	....	....	......	....	......	Do.
663	1	12	F.	....	....	....	......	....	....	....	......	....	......	Bright steely.
664	1¼	20	V. 20	20	C. 45	20	½ F.	....	....	....	......	....	......	Lot March, 1877; dull gray fiber.
665	1	8	C. 55	5	½ F.	....	......	....	....	....	......	....	......	Half gray fiber, and half fine steely.
666	....	....	....	....	....	....	......	....	....	....	......	....	......	
667	2¼	45	□	....	....	....	......	....	....	....	......	....	......	Bright granulous.
668	"	37	□	....	....	....	......	....	....	....	......	....	......	Do.
669	"	30	C.	30	□	....	......	....	....	....	......	....	......	Do.
670	"	30	C.	25	+	10	F.	....	....	....	......	....	......	Do.
671	2	25	□	....	....	....	......	....	....	....	......	....	......	Do.
672	"	20	□	....	....	....	......	....	....	....	......	....	......	Do.
673	"	18	C.	10	F.	....	......	....	....	....	......	....	......	Do.
674	"	19	□	....	....	....	......	....	....	....	......	....	......	Do.
		Px.												
675	"	30	V. 20	30	T. C. 40	30	+ 70	30	T.B. 117	....	......	....	......	Long, gray fiber. See Plate XII.
676	1¾	30	T.C. 40	30	T. B. 75	....	......	....	....	....	......	....	......	Do.
677	1⅝	25	T.C. 50	25	T.B. 110	....	......	....	....	....	......	....	......	Do.
678	1½	10	T.B. 110	....	....	....	......	....	....	....	......	....	......	Do.
679	1⅜	30	V. 25	30	S. C. 45	30	+ 60	30	+ 80	30	TC. 90	30	+ 110	Loose, gray fiber, soft.
680	1¼	30	S. C. 40	30	□	....	......	....	....	....	......	....	......	All bright granulous.

This iron (P) tested by tension, and judged by ductility, &c., in the bar form, gave most excellent results, and impact and bending-cold tests of extreme degree were well endured while the surface of the bar remained intact, but a very slight nick or score deprived it of all power to resist.

The bars of 2¼″ and 2″ were made for experimental purposes, and the manufacturer being present during the tests, conceived that he had discovered the cause of the defects, and prepared the bars Nos. 675 to 680, of P*x*, which, tested as chain links and by impact, gave evidence of great improvement, the previous bars of P having been deficient in welding qualities, a fault that was inherent, as shown by the surfaces of fractures, which presented a laminated appearance, showing that the welding of the crude slabs had not been complete.

With the exception of those made upon hammered iron and iron A, the tests recorded in the following tables were made upon unscored test-pieces. In all cases the length of the test-piece was equal to twelve times the diameter. The blows were of the 100-pound hammer, dropped 30 feet, and were delivered as rapidly as possible, the average interval being about one minute. After the tests by impact-hammer, such pieces as remained unbroken were closed down under the steam hammer. Those which closed completely, without crack, are marked *

Comparative stiffness as developed by impact.

Test number.	Iron.	Diameter of bar.	Deflection at each blow.								Remarks.
			First.	Second.	Third.	Fourth.	Fifth.	Sixth.	Seventh.	Eighth.	
		″	°	°	°	°	°	°	°	°	
681	H. I.	2	18	30	42	53	62	95	......	......	
682	H. I.	"	20	33	44	70	93	110	......	......	
683	A.	"	27	43	50	73	94	109	......	......	
684	A.	"	29	43	68	78	96	111	....	......	
685	D.	"	21	40	50	63	77	90	107	......	Slight crack.
686*	F.	"	22	35	48	60	75	89	96	109	
687*	F. *x* 1	"	19	32	46	60	73	80	90	107	
688*	F. *x* 8	"	20	40	60	75	86	102	114	......	
689	N.	"	40	80	□	......	......	......	......	......	Square break.
690*	O.	"	17	32	50	64	80	105	115	......	
691	P.	"	20	43	60	65	70	93	105	111	Slight crack inside crown.
692*	P. *x*	"	20	35	50	63	75	100	112	......	
693	D.	$1\frac{7}{8}$	24	41	65	80	92	103	......	......	Slight crack inside crown.
694*	F.	"	27	43	62	78	100	109	......	......	
695*	F. *x* 1	"	25	41	58	70	90	98	108	......	
696*	F. *x* 3	"	25	45	65	78	92	110	......	......	
697	N.	"	40	□	......	......	......	......	......	......	
698	O.	"	22	45	70	98	112	......	......	......	Slight crack inside crown.
699	P.	"	19	40	65	72	81	100	111	......	Crack across crown.
700	O.	$1\frac{3}{4}$	30	53	78	90	110	......	......	......	Slight crack inside crown.
701*	F.	"	34	60	72	95	110	......	......	......	
702*	F. *x* 1	"	30	50	70	90	110	......	......	......	
703*	F. *x* 3	"	28	56	75	98	117	......	......	......	
704	N.	"	28	53	74	100	110	......	.....	......	Broke while closing down.
705	O.	"	27	53	74	101	115	......	......	......	Slight crack across butt.
706	P.	"	25	51	72	88	112	......	......	......	Slight crack inside crown.
707*	P. *x*	"	32	50	65	90	110	......	......	......	
708	D.	$1\frac{5}{8}$	40	65	90	112	......	......	......	......	Slight cracks inside crown.
709	F.	"	39	64	90	111	......	......	......	......	Slight cracks inside crown.
710*	F. *x* 1	"	35	60	88	109	......	......	......	......	
711	F. *x* 3	"	35	68	94	112	......	......	......	......	Cracked across butt.
712	N.	"	30	60	□	......	......	......	......	......	Square break.
713*	O.	"	50	60	78	110	......	......	......	......	
714	D.	$1\frac{1}{2}$	50	80	115	......	......	......	......	......	Slight cracks across crown.
715*	F.	"	46	82	107	......	......	......	......	......	
716*	F. *x* 1	"	40	80	107	......	......	......	......	......	
717*	F. *x* 3	"	45	80	110	......	......	......	......	......	
718	N.	"	45	85	115	......	......	......	......	......	Broke while closing down.
719*	O.	"	35	70	115	......	......	......	......	......	
720*	P.	"	45	80	110	......	......	......	......	......	
721	D.	$1\frac{3}{8}$	55	86	115	......	......	......	......	......	Slight cracks inside crown.
722*	F.	"	60	97	116	......	......	......	......	......	
723*	F. *x* 1	"	57	98	120	......	......	......	......	......	
724*	F. *x* 8	"	60	110	......	......	......	......	......	......	
725	N.	"	55	110	......	......	......	......	......	......	Broke in two while closing down.
726*	O.	"	60	114	......	......	......	......	......	......	
727*	D.	$1\frac{1}{4}$	70	112	......	......	......	......	......	......	
728*	F.	"	76	110	......	......	......	......	......	......	
729*	F. *x* 1	"	72	112	......	......	......	......	......	......	
730*	F. *x* 8	"	75	114	......	.....	......	......	......	......	
731	N.	"	74	115	......	......	......	......	......	......	Broke in two while closing down.
732*	O.	"	78	110	......	......	......	......	......	......	
733*	P.	"	60	110	......	......	......	......	......	......	
734*	D.	$1\frac{1}{8}$	75	110	......	......	......	......	......	......	
735*	F.	"	103	......	......	......	......	......	......	......	
736*	F. *x* 1	"	90	112	......	......	......	......	......	......	
737*	F. *x* 3	"	105	117	......	......	......	......	......	......	
738	N.	"	100	......	......	......	......	......	......	......	Broke while closing down.
739*	O.	"	110	......	......	......	......	......	......	......	
740	P.	"	100	......	......	......	......	......	......	......	Cracked while closing.
741*	P. *x*	"	80	110	......	......	......	......	......	......	

PART II.

SECTION I.

THE CHAIN CABLE.

STRUCTURE OF THE LINK — METHOD OF MANUFACTURE — SOURCES OF WEAKNESS IN THE WELD-STUD — A HIGH TENSILE STRENGTH — COMPARISON OF STRENGTH OF STUDDED AND UNSTUDDED LINKS — COMPARISON OF STRENGTH OF END AND SIDE WELDS — EFFECT UPON STRENGTH OF UNDER AND OVER WORK — METHOD OF TESTING CHAIN CABLES — PHENOMENA OBSERVED AND RECORDED — TABULATED RECORD OF STRENGTH OF SHORT SECTIONS AND SINGLE LINKS — WEIGHT OF CHAIN CABLES, WITH SUGGESTIONS FOR REDUCTIONS.

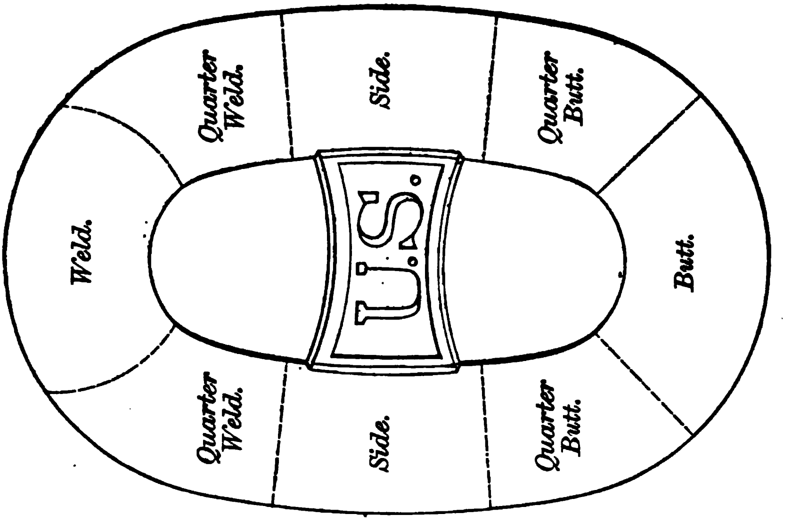
SECTION II.

PROOF STRAINS FOR CHAIN CABLES, WITH RECOMMENDED PROOF TABLE AND METHOD OF CONSTRUCTION.

SECTION I.

THE CHAIN LINK.

The sketch will show the parts of the links designated as quarter-weld, weld-butt, &c.



1⅜" LINK, HALF-SIZE.

A chain link consists of a bolt of round iron, which has been bent to an oval form, and the ends welded together. A stud, generally of cast iron, is introduced, to prevent closure of the sides when subjected to tension, and kinking of the chain when being stowed in the locker.

"Close links" are made in the same manner, omitting the stud. These are generally of small size.

The bolt for studded chain is generally of length equal to twelve times the diameter; for "close links," eleven times.

It is evident that the greatest strength which can be developed by the link cannot exceed that of the combined strength of the two sides, and to this it would be necessary that the single sectional area of each end of the link should be capable of resisting to an equal amount a transverse strain.

In practice it is found that no link can be made which is twice as strong as the bar from which it is produced. Various causes operate to reduce the 200 per cent. of the strength of the bar to a much lower proportion. Among these causes are those due, first, to peculiarities of the iron; second, to the process of manufacture, and; third, to the effect of the stud.

The information gained by the tests upon round bars guide us in the selection of iron which will *probably* make good chain cable; but it does not supply all that is needed.

Tension tests show the power of the bar to resist steadily applied strain, and impact tests indicate the relative power of various irons to withstand suddenly applied strains upon a transverse section; hence from these we gain an idea as to the possible strength of the sides and ends of the links, but no knowledge whatever as to the condition of that portion of the link upon which the *weld* has been made.

The process of manufacture involves twice reheating and hammering the ends of the bolts, once to shape the *scarfs*, and once to weld; while the middle of the bolt, which forms the *butt* of the link, receives much less heating, and no hammering. Thus the *weld* and *butt* ends have received very different treatment, and each end of the link has been subjected to weakening causes, peculiar to itself, the effect of which cannot be foreseen, and which effect varies greatly with the character of the iron.

The forging and reheating have, if the iron has already been suitably worked, a tendency to lower the elastic limit and strength of the weld end, and the process of bending affects some irons, notably those which are red-short, injuriously, thus weakening the butt of the link. And the introduction of the comparatively incompressible cast-iron stud alters the nature of the strains, and with common coarse chain iron proves a source of weakness.

If through none of these causes the normal strength of the bar is lowered, and if through its arched form the end of the link is made as strong as the two sides, we have a link whose strength equals 200 per cent. of that of the bar. With this then, for a standard, we consider that the bar iron, which in link form develops with the greatest uniformity the greatest proportion of this percentage, is the most suitable for chain cables, and that the development of a low or irregular percentage indicates the opposite.

The degree of divergence from the standard 200 per cent. indicates the relative value of various irons for chain cables.

The most common source of weakness of chain links is the *weld*, and the degree of weakness from this source depends first upon the character of the iron, and second upon the skill and judgment of the chain-welder, who has it in his power to make a worthless link from the best iron, and to utterly deprive the results of competitive tests of their value.

With all irons the weld end of a link is the weak end. With some, the loss of strength by ordinary welding is so great that, however valuable they may be for other purposes, as chain iron they are worse than worthless.

The following data, as to location of rupture, demonstrates clearly the above statement to be true:

Location of ruptures of 435 *links.*

Iron.	Number of tests.	Ruptures at weld, 333.		Ruptures at butt, 86.		Side, 16.
		Quarter.	Through.	Quarter.	Through.	
A	37	12	2	15	3	5
B	45	35	9	1		
C	57	33	5	9	4	6
D	20	16	1		1	2
E	25	18		7		
F	26	14	5	3	4	
F*x*	8	4	3	1		
G	5	5				

Location of ruptures of 435 *links*—Continued.

Iron.	Number of tests.	Ruptures at weld, 333.		Ruptures at butt, 86.		Side, 16.
		Quarter.	Through.	Quarter.	Through.	
H	3	2	....	1	....	....
J	5	5	....	....	....	....
K	23	18	1	4	....	....
L	6	4	2	....	....	....
M	124	27	79	11	4	3
N	8	6	2	....	....	....
O	9	5	2	1	1	....
P	29	12	2	11	4	....
Px	5	1	3	1	....	....
	435	217	116	65	21	16

Thus in the rupture of 435 links, 333 of them broke at the weld end, 86 at the butt end, and 16 on the side.

The most ordinary location of the rupture, if we except irons F*x*, F, L, M, and P*x*, was at the quarter of the weld, which rupture is produced by a resolution of the force of direct tension and the resistance opposed by the stud.

F*x*, F, and P*x* were all irons which had received a great amount of work, and whose welding qualities were by it impaired. L was a weld-steel, and iron M, which furnishes 79 out of the 116 ruptures through the weld, was of a most complex structure, as may be seen by the tables of analysis. Copper, phosphorus, silicon, nickel, and, in some cases, chromium gave to this iron most remarkable qualities.

An examination of the records of the strength of links and of the percentage of the bar's strength developed by the links will show that all of those links which broke "through the weld" were very weak and irregular in both factors. Hence, an iron whose weld is, through any cause, unreliable is not suitable for cable.

Among the causes which produce deficiency in welding properties, there are two which produce great *tenacity* in the bar, viz, chemical peculiarities and excessive work; therefore, when excessive tensile strength is found to exist in a bar as tested by tension, it should be regarded as a probable indication of deficient welding properties. As may be seen by the record of tension and impact compared, high tenacity in the bar frequently indicates a lack of power to resist sudden strains. Therefore, in judging iron by tensile strength alone, it should be considered as more than probable that the strongest bars will produce the weakest cables, although there will undoubtedly be in each of such cables a few links with greater strength than can be developed by irons of less tenacity.

THE WELD.

A few notes in regard to the weld may have a value, as they are founded upon observation in the shop.

In making 150 fathoms of chain, which length generally constitutes a cable, there are of welds from 2,925 in 1″ to 1,500 in 2″. These are probably made by a dozen different chain-welders, each of whom has a habit, which he will not readily change, by which he judges of the proper heat and the degree of rapidity with which he should make his weld. Different welders have very different ideas and, unless the iron which is being worked on will permit considerable variation in the temperature, it is probable that the resultant links will vary greatly in value. If eleven out of the twelve judge correctly, the error of the other man may render valueless all of their labor.

Irons in which there is much carbon require to be welded at a very low heat; phosphorus in excess calls for the same. Coarse iron with much slag requires a high heat and hard hammering, and even then there is a liability for "faces" to form throughout the whole surface of the lap, which faces simply stick together and are liable to draw. A very close, fibrous iron also requires a high heat and hard, rapid hammering; the reason for which is that the heavy blows previously required to make the scarf or lap have so amalgamated the fibers one with another that when the two laps are brought into contact the fibers of each do not intermingle thoroughly, and they, too, are frequently simply stuck together, adhesion taking the place of a process similar to felting, which occurs in welding an iron with a rather open fiber. With this a low heat is required, which seems to penetrate and expand the fibers so that they intermingle and the two laps are held together by a net-work. Moderate hammering is necessary with this type of iron, which is seldom found to possess great tensile strength, but nearly always has great resilience.

An iron in which sulphur is in excess can be bent and welded at a high heat, but the more moderate heat at which the bend and scarf are usually made is trying to it, and "*red-short links*" are frequently cracked in bending.

Comparison of value of end and side welds.

The weld thus, as has been shown, proving its claims to be considered as the weak place of the link, it was considered desirable to ascertain if a change in its location would have any tendency to strengthen it. At some private manufactories a system has been introduced of making the weld upon the side of the link by means of a machine which bent and welded the link at one operation. We procured a number of short sections of cable which had been made in this manner, purchasing them from the manufacturer, who, at the same time, supplied us with a few bars of the iron from which the cable was made; from these bars we prepared links in the usual manner, and connected sections of the machine-made side-welded links with the hand-made end-welded ones, and subjected these combined sections to tension.

Eight such tests were made, and in *every case* the weld of the machine-made link *drew* apart at the following strains, the iron being $1\frac{1}{8}''$ in diameter, viz: 80,830 pounds, 78,144 pounds, 76,608 pounds, 56,640 pounds, 88,280 pounds, 65,660 pounds, 83,520 pounds, 67,000 pounds.

Three of the couplets of end-welded links, which had resisted the strains which had broken the side-welded links with which they were connected, were retested, and broke at 89,000 pounds, 97,000 pounds, and 98,000 pounds.

In order to ascertain whether the deficiency in strength of the side-welded links was due to the location of the weld or to their having been made by machine-work, a set of couplets (two links connected) was made, of which in each case one link was welded upon the side and the other upon the end, all being made by the same smith. Upon testing these couplets (two in number) in one case the side weld drew at 81,000 pounds, and in the other it broke where welded at 87,200 pounds. The two end-welded links were then broken at 99,000 and 101,000 pounds.

These experiments indicate that we cannot strengthen the link by changing the location of the weld, and our only resource is to select such iron as is least injured by the process of welding.

THE STUD.

Discussion of its effect upon the link.

The second cause which tends to reduce the strength of links made from certain types of iron is the *stud.*

Our experiments lead us to consider that the opinion which is generally entertained, and which is backed by the most eminent authorities, that the studded link is stronger than the unstudded one made from the same iron, is erroneous, both in principle and in fact.

Rankin, in his "Manual of Machinery," says, "An unstudded chain has about two-thirds of the strength of a studded chain of the same diameter of wire."

John Anderson, LL. D., superintendent of machinery to the War Department, Woolwich, in a work published in 1872, says, "It is to be noted, whatever the explanation may be, that the stayed-link chain, when made of the same diameter of iron as the open-link, is stronger than the other in the proportion of 9 to 6; the office of the stud is to prevent the collapse of the link and thereby intercept the shearing action due to the wedge action of one link within the other."

American authorities coincide with the above opinions, with which, however, we entirely differ. Theoretically it should not be stronger, actually it is weaker than the open-link, especially if both are made of coarse brittle iron.

To discuss the case in its most general aspect, we will consider the link to be reduced to a line, and in the accompanying diagram let the lateral points represent the extremities of this line and the upper and lower points PP the extremities of the stud.

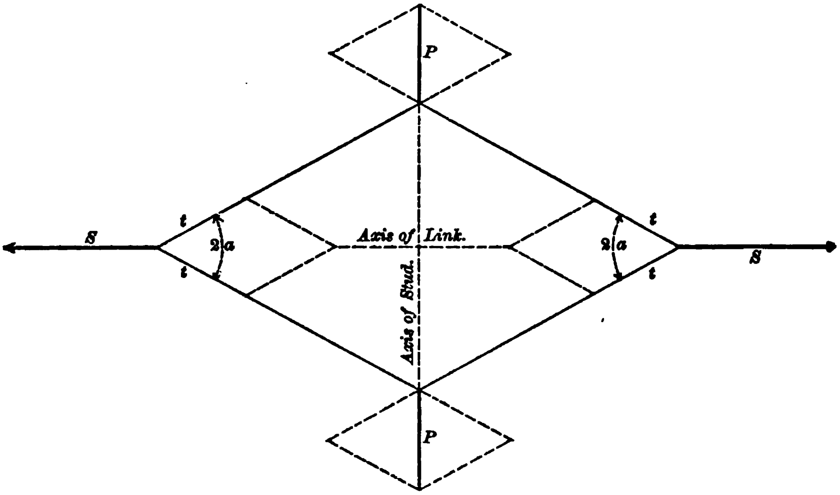


Diagram illustrating the action of the stud.

A strain being applied longitudinally sufficient to produce a change of form in the link, the tendency of the component of the tension at a right angle to the axis of the link to draw the sides together is resisted by the stud, and we have at either of the four points of the link the familiar case of a load applied to the middle point of a line whose extremities are fastened.

Representing the total strain upon the cable by S, the tension on either side of the link by t, the resistance of the stud by p, and the angle at either vertex by $2a$, the parallelogram of forces gives the resolution indicated by the diagram, and the equation—

$$\begin{aligned} S &= 2t \text{ cosin } a &&= p \text{ cotan, } a \\ p &= S \tan a &&= 2t \sin a \\ t &= \frac{S}{2 \cos a} &&= \frac{p}{2 \sin a} \end{aligned}$$

Supposing a constant strain S, as the angle a increases, t and p increase rapidly, to the extreme case of $a = 90°$, when t and p are infinite.

Of these four quantities, the interdependent relations, which are so manifest in theory, will be modified in practice by the character of the iron from which the link is made.

The equations indicate that when the links are without studs they might stretch until they nipped each other and then be in the best possible position to resist stress, the sides being parallel and separated but by their own diameter, the ends so closed together that the stress is received and transmitted through bearing surfaces much greater than before the parts had yielded to stress.

Our experience in testing cable-links showed us that with all classes of iron this tendency to assume the strongest possible form existed, but in very different degrees, and in this difference we find a possible reason for the different conclusions that have been arrived at by the English experimenters and by ourselves. The English use for chain-cables iron of great tenacity, and the studs to their links are made of malleable iron.

Our experiments have been made both with links of iron of similar character and with others made from iron with medium and low tenacity, but with great ductility and power of flexure. In all cases we have, however, used the ordinary cast-iron stud.

The links made from ductile iron would under tension assume as closely as possible the strongest form, as indicated by the equation.

One side of the link would become straight, pressing the stud against the other side, until the latter had buckled to considerable extent, when the rupture would take place upon this greatly arched side, the iron tearing apart as shown in Figs. 1, 2, and 3 in the accompanying illustration.

If the link were made of coarse, hard iron, with little ductility, the stress upon the sides would not be relieved by the closure of either, but, both resisting the change of form, would yield to the stress, which would be resolved by the stud's resistance into a transverse strain, and the link after rupture would appear as is shown in Figs. 6 and 7 of the illustration, the fracture being nearly at right angles, and showing a square cut across the fibers. If made of iron with defective welding properties, one link would cut its way through the welded end of the other at a stress not sufficient to either produce closure or break the iron where it had not been forged. Fig. 5 illustrates this type of fracture, it being taken from a link of iron M.

Fig. 4 illustrates the type of fracture common to a very soft iron, which occurs sometimes through the weld end and sometimes through the butt. In some respects it resembles that shown in Fig. 5, but examined, it will be seen that in case of the latter there was no reduction of area at fracture and no indication of an attempt to close, while in Fig. 4, with one side nearly straightened and the iron near the fracture reduced greatly, it can be seen that simple lack of the necessary hardness was the cause of the break through the end.

Fig. 4 is from a link of iron F, which was very ductile; the diminution of area was so great that sufficient was not left to resist the stress.

Experiments made upon iron of the type shown in Figs. 1, 2, and 3, showed that the excess of the strength of the unstudded link over that of the studded ranged from 12 to 17 per cent., averaging about 15 per cent. of the strengthof the studded links, while with links made of iron from the class shown in Figs. 6 and 7, the excess of strength was about 5 per cent., as shown by the following tests:

Experiments upon comparative strength of studded and unstudded links made from soft, ductile irons (C *and* F). *Diameter of iron* 1⅛″.

The links were arranged in seven section of three links each, of which the center link was in each case an open one, and the two end links (E L) of the test were connected to the proving-bar by means of links of considerably greater diameter (1$\frac{7}{16}$″). The stress being thus transmitted and received through bearing surfaces of greater extent than in case of the open links, they should have resisted more strain had the strength of the two styles of link been equal.

After pulling each section until one of the links broke, the pair remaining, was again pulled till one broke, and finally the unbroken remaining link was broken.

The results of tests were as follows:

Test number.	Number and arrangement of links.		Link which broke.	Stress at rupture.
				Pounds.
1	3	Stud, Open, Stud.	S.	87, 360
1	2	O., S.	S.	89, 088
1	1	O.	E. L.	86, 400
1	1	O.	E. L.	74, 880
2	3	S., O., S.	S.	91, 584
2	2	O., O.	O.	99, 844
2	1	O.	E. L.	77, 280
2	1	O.	O.	82, 170
3	3	S., O., S.	S.	96, 960
3	2	O., O.	E. L.	92, 544
3	2	O., O.	O.	104, 064
4	3	S., O., S.	Pin.	85, 632
4	3	S., O., S.	S.	98, 688
4	1	O.	E. L.	96, 000
4	1,	O.	O.	104, 000
5	3	S., O., S.	S.	90, 624
5	1	O.	O.	105, 576
6	3	S., O., S.	S.	82, 176
6	2	O., S.	S.	91, 776
6	1	O.	O.	100, 128
7	3	S., O., S.	S.	79, 488
7	2	O., O.	O.	105, 600
7	1	O.	E. L.	67, 200
7	1	O.	E. L.	89, 280
7	1	O.	Pin.	82, 176
7	1	O.	O.	109, 682

The bar from which sections Nos. 1 and 2 were made had a tensile strength of 59,000 pounds; Nos. 3 and 4 were from bars with tensile strength of 57,000 pounds; Nos. 5 and 6 from bars with 54,000, and No. 7 from a bar with 57,700 pounds tensile strength.

In every case when there were both open and studded links connected the studded link first broke. In six tests the open link of 1⅛″ diameter of good iron broke the 1$\frac{7}{16}$″ link of inferior iron, and twice the shackle-pin of steel.

The maximum strength of the studded links on the first pull was 96,960 pounds; the minimum, 79,488 pounds; the average of six, 88,030.

In three cases where a studded link was pulled the second time, the maximum strength was 98,688 pounds, minimum 89,088 pounds, and average 93,188 pounds.

The maximum strength found in an open link was 109,632 pounds on a *sixth* pull, the next 105,576 on a *second* pull, and the minimum upon any pull was 82,170 pounds, the average strength of eight being 101,327 pounds, the inferior iron (contract chain-iron) of which the end links were made breaking upon second and third pulls, at from 67,200 pounds to 96,000 pounds, averaging 82,383 pounds. From which we deduce that of the same iron an unstudded cable would have exceeded in strength the studded one in actual strength over 13,000 pounds, or 15 per cent., and that after having been subjected to stress sufficient to break the studded links the unstudded cable would have still proved reliable; and, further, that a vessel provided with a studded cable, made of this good chain-iron of 1$\frac{1}{8}$″ diameter, of which 150 fathoms would weigh five tons, would have possessed more reliable ground-tackle than if the cable had been of the 1$\frac{7}{16}$″ contract-iron, weighing eight tons.

During the experiment recorded, several times it happened that, either through the stress or the recoil, one of the studded links became an open one by the stud splitting and flying out.

A second series of experiments was made with links made from iron B, a strong but brittle iron with good welding qualities. Ten pairs of open links and ten of studded links were prepared and tested by tension, with results as follows:

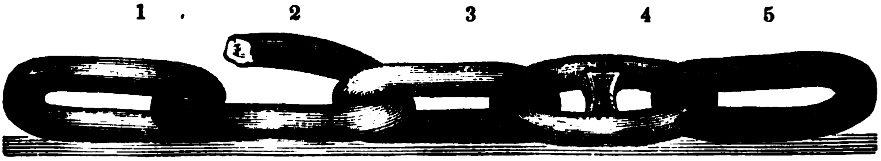
Comparison of the strength of studded and open links of iron B. Size of iron, 1$\frac{7}{16}$″.

Studded links.				Open links.			
Number of test.	Stress in pounds at—		Stretch of unbroken link.	Number of test.	Stress in pounds at—		Stretch of unbroken link.
	First stretch.	Rupture.			First stretch.	Rupture.	
			″				″
1	62,000	154,000	1.06	11	49,200	158,400	1.25
2	62,500	149,000	1.50	12	55,700	156,800	1.30
3	59,000	150,000	1.50	13	46,000	164,650	1.75
4	56,000	152,000	1.50	14	49,000	157,000	1.62
5	57,700	151,700	1.44	15	53,000	159,500	1.44
6	59,000	139,600	1.20	16	50,000	163,200	1.76
7	57.500	140,000	1.20	17	50,000	160,000	1.25
8	57,000	154,700	1.20	18	57,000	151,700	1.44
9	....	152,600	1.44	19	55,000	147,300	1.32
10	62,590	155,040	1.12	20	50,000	152,000	1.12
	59,250	149,864	1.32		51,490	157,055	1.45

The average strength of the open link exceeded that of the studded 7,191 pounds, or 4.8 per cent. of the strength of the latter, and seven of the open links were stronger than the strongest of the studded ones.

The lower stress at which the form of the open link begins to change, and the increased elongation produced by stress, indicate that the stud has its value, but in its use it is desirable to know its exact effect.

The appearance of links with and without stud, when strained to the point of rupture of the former, is shown in the accompanying cut, which is taken from a photograph of a section of iron O, 1$\frac{3}{4}$″ links, which broke at a stress of 207,000 pounds.



The first, third, and fifth links were without stud, the second and fourth studded, the rupture taking place on the second link, it being the nearest studded link to the engine which produced the stress.

With links made from a ductile iron, the stud preventing closure of the sides, the two ends are drawn down to a lozenge shape, or one side of the link straightens, while the other, being forced outward, tears apart at the quarter, the weld being frequently pried open.

If the material is coarse and not ductile, the sides will break transversely through the leverage of the stud.

Whatever the nature of the material of which the link is made, the stud is a source of weakness, it causing the brittle iron to break transversely, and subjecting the more ductile to undue crushing and shearing.

In addition to the evidence given, abstracts from our tests show that in breaking 33 sections of links of irons F*x*, D, O, and N, which were composed of both studded and unstudded links, in 29 cases the link which broke was a studded one.

From the facts recorded, we feel that we are justified in saying that, beyond doubt, when made of American bar-iron, with cast-iron studs, the studded link is inferior to the unstudded one in strength.

Therefore we place the stud as next to the weld among the elements which tend to prevent the individual links from developing the utmost possible strength.

NOTE BY THE EDITOR.—Although the evidence furnished by daily repetitions of experiments, for a period of nearly two years, was sufficient to convince all who were engaged in the practical work of testing chain-cables to destruction, that the unstudded link was stronger than the studded, yet the portion of such evidence embodied in the preceding paper, failed to settle the question definitely, and the views advanced, have, since the publication of this report, been subject to adverse criticism, not only in this country, but in the columns of several English journals and papers. But one of the articles published, in which issue was taken with the conclusions of the United States board, gave any facts or data to support the assertion that we were evidently wrong. The article referred to was, however, one the source of which entitled it to credit, for it was based upon the results of a series of experiments carried on by order of the Bureau of Equipment of the Navy Department by officers of the Navy, at the navy-yard in Washington, and the tests were made by the same machine which had been used by the board, and from this series of experiments, almost identical in their nature with those which had been carried on by the editor, and upon which the views of the board in regard to the effect of the stud were based, a conclusion was drawn which was directly the opposite of that of the board; and this conclusion was embodied not only in an official report, but in an article on chains and chain-iron, which was published in the Quarterly Service Magazine, of August, 1880, as follows:

"There is a great difference of opinion as to what, if any, benefit there is to the chain by the introduction of the stud. It has always been held until lately that the cable is thereby increased in strength. Luce in his Seamanship, says 'the cable is strengthened one-fourth,' while Beardslee in his Iron-Board Tests, says 'the stud weakens the chain.'

One hundred triplet samples were made expressly for test, 40 of them without studs, 30 with cast-iron, and 30 with wrought-iron studs; these, on being pulled to destruction, stood as follows: wrought-iron studs, first; cast-iron studs, second; without studs, last."

This result, so opposite to those obtained by the committee of the board, naturally attracted the attention of the chairman, under whose supervision the tests recorded by the board's report had been made, and who was responsible for the views arrived at, whether erroneous or otherwise, and the chief of the bureau of equipment, Commodore Earl English, U. S. N., very kindly acceded to his request, and not only furnished to him a copy of the report in detail of the experiments, but authorized a further investigation of the subject.

The following is the record in detail of the strains at which the links referred to were broken:

[Abstract from records at navy-yard Washington, D. C.]

Competitive tests upon 100 *short sections of* 1⅝″ *chain links*—3 *links in each section.*

[30 fitted with cast-iron studs; 30 fitted with wrought-iron studs; 30 of full-length bolt without studs; 10 of shortened bolt, without studs. Tests were made in January, 1880.]

Number of test.	Studded links.				Unstudded Links.			
	Cast iron.		Wrought iron.		Full size.		Close links.	
	Strength.	Where broken.	Strength.	Where broken.	Strength.	Where broken.	Strength.	Where broken.
	Pounds.		*Pounds.*		*Pounds.*		*Pounds.*	
1	158, 600	Qr. W	173, 000	Qr. W	157, 600	Thro. W	145, 600	All through weld end of links.
2	168, 600	Thro. W	164, 000	do	186, 600	Qr. W	165, 000	
3	171, 000	Qr. W	175, 000	Thro. W	175, 600	do	148, 600	
4	172, 000	do	158, 600	Qr. W	170, 000	do	177, 600	
5	165, 000	do	176, 600	do	120, 000*	Thro. W	128, 600	
6	167, 000	do	159, 600	do	177, 600	Qr. W	145, 600	
7	162, 000	Thro. W	169, 600	do	143, 000*	do	137, 600	
8	163, 000	Qr. W	161, 600	do	156, 000	Thro. W	....	
9	153, 000	do	166, 600	do	155, 000	do	152, 000	
10	152, 400	Thro. W	156, 600	Thro. W	154, 000	do	165, 000	
11	175, 000	Qr. W	153, 000	Qr. W	178, 000	do	172, 000	
12	177, 600	do	160, 000	do	110, 000*	Thro. sides	**158,760**	
13	163, 000	do	184, 000	Thro. butt.	163, 000	Thro. W		
14	153, 000	Qr. butt	179, 600	do	159, 600	do		
15	155, 000	Qr. W	183, 000	Qr. W	162, 000	do		
16	162, 000	do	169, 600	do	163, 000	do		
17	163, 000	do	185, 000	do	166, 000	Qr. W		
18	167, 600	Thro. W	168, 600	do	135, 600*	do		
19	168, 600	do	155, 600	do	138, 600*	Thro. W		
20	163, 000	Qr. W	145, 600*	Thro. W	117, 600*	do		
21	175, 000	do	162, 000	Qr. W	172, 000	Qr. W		
22	175, 000	do	154, 000	do	165, 000	Thro. W		
23	168, 600	do	178, 600	Thro. W	168, 600	do		
24	176, 000	do	173, 000	Qr. W	163, 600	Qr. W		
25	147, 600*	do	174, 000	Thro. W	174, 000	do		
26	162, 000	Thro. W	145, 600*	Qr. W	155, 600	Thro. W		
27	168, 600	do	165, 600	Qr butt	167, 600	do		
28	168, 600	do	157, 600	Thro. W	175, 000	Qr. W		
29	167, 600	do	178, 000	Qr. side	155, 600	Thro. W		
30	163, 000	do	160, 000	Thro. W	135, 600*	do		
Av.	**165,080**		**166,266**		**157,218**			

* Tests marked * are referred to in the following discussion.

The bolts from which the ten sections marked "close links" were made were shortened from 12 to 11 diameters.

The officer under whose supervision the foregoing tests were made, after a discussion of the data, concludes as follows: "It is found, contrary to Commander Beardslee's book on chain cables, and the report of the United States board that cables with studs are stronger than those without them (this is with iron manufactured at the equipment rolling-mill), and agrees with results obtained in England upon other irons."

After careful examination of the data furnished, the editor fails to perceive that its nature is such as to present any proof that the views hitherto expressed by the United States board are erroneous, and he would respectfully submit the following analysis and discussion of the evidence:

The question is, simply, which is the stronger, a link with, or one without a cast-iron stud, and the data as furnished is of a nature that it can be used to prove either or both sides of the question.

For our purposes it will be treated exactly as have been all other collections of data from which the conclusions given in this report have been drawn, and the facts given will not be twisted or warped to fit any preconceived theory.

First, the *means* as given will be considered. If the evidence presented by them is to be accepted as conclusive, the verdict in favor of the superior strength of the studded links is not without foundation, for the mean of breaking strains of 30 of this type, exceeds that of 30 unstudded links by 8,000 pounds.

The question arises, is this difference so great that it is beyond doubt due to the presence or absence of the stud? If links of the same type differ in strength by equally as great an amount it will be fair to assume that this difference may be due to some cause other than the stud.

Examining first the recorded breaking strains of the 30 studded links, we find between the maximum strength, 177,600 pounds, and minimum, 147,600 pounds, a difference of 30,000 pounds; between the pair next to maximum and minimum, viz, 176,000 and 152,400, a difference of 23,600 pounds; between the next pair a difference of 22,000 pounds; and it is not until the sixth pair, viz, Nos. 3 and 6, is reached that the difference diminishes to that which exists between the two varieties, and there are 10 of the 30 sections tested which differ from the average strength of the series by more than 9,000 pounds. The other type presents the same irregularities within itself.

Therefore it cannot be considered as certain that the difference of 8,000 pounds between the two types settles the question, for compared with the differences existing in strength of links of the same type it is but trifling.

The next question which arises, is as to the propriety of incorporating in "means" results which are evidently anomalous. In the construction of the various tables of this report such results are given, for they funish valuable evidence upon other points, such as uniformity of iron, skill, or want of it, of the chain-welder, &c., but they are not allowed to affect the value of means, by distribution of the defects of individual samples among many which do not present evidence that they also are defective. Averages to have value should be made up of factors of some uniformity. For instance, the weight of chain cables of different sizes cannot be ascertained even approximately by an average obtained from irregular numbers of 1″ and 2″ chains; neither can the normal strength of any size or type be predicated by an average made from tests of well-made and badly-made links. There is a positive limit to the strength of a well-made link; it cannot exceed 200 per cent. of the bar's strenght. There is *no* limit to the amount of deterioration which can be caused by *burned welds*.

In classifying certain results as anomalous, and due to faults incident to the individual cases it is necessary to establish a standard, wide variation from which should justify suspicion.

In the present examination the standard sought for is the normal strength of a section of chain link made from 1⅝″ iron, suitable for chain cables.

The table on page 207, "Probable strength of cables," furnishes a standards which are the results of much study. In it we find that the maximum, average, and minimum strengths for the size are 182,000, 174,500, and 166,000 pounds (round numbers). Comparing the records under discussion with these standards we find, first, that the average strength of the 60 studded links, 165,670 pounds, approximates closely to the minimum, and that of them none of those with cast-iron studs reach the maximum, which is exceeded by three with wrought-iron studs, and equaled by the mean of five of the latter; hence strength approximating to 182,000 pounds need not be considered as anomalous, and the average standard is equaled by the mean of ten of the cast-iron studded links and by that of fifteen of those with wrought-iron studs.

Of the sections without studs we find that one test, No. 2, exceeds the maximum, and the mean exceeds the average standard.

From this we can deduce that the normal strength of many of these sections of both types was fully up to the standards, and that in every case where a comparatively low strength was found it was due to some cause other than the stud, and that such result should not be allowed to enter into the solution of the problem.

Previous experiments have determined that the greatest variation from the standards which should be allowed is 10 per cent.; beyond this there is in all probability a defect in the links, and to obtain a fair average of the strength of the sections under investigation none which broke under 150,000 pounds should be counted.

Omitting from the record such breaks, we eliminate from cast-iron studded links No. 25, from the wrought-iron studs Nos. 20 and 26, and from those without studs Nos. 5, 7, 12, 18, 19, 20, and 30.

With this correction the means become 29 cast-iron studs, 165,680 pounds; 28 wrought-iron studs, 167,730 pounds; 23 without studs, 165,870 pounds; or, making a general average, the mean of 80 tests of 1⅝″ links is 166,468 pounds, from which neither of the types vary *one per cent.*

The reason why so large a proportion of the defective links were of those without studs cannot be ascertained with certainty. In our judgment the absence of the stud had no influence whatever, and the weakness was probably due to unskillful welding; the iron was probably *burned.* Whether the preponderance against the studless link was due to accident or design can be only conjectured, but it is noticeable that while but 18 of the 60 (30 per cent.) studded links broke through weld, 19 of the 30 (or 63 per cent.) unstudded met with this fate, which has been pronounced evidence of bad welding.

Bringing into the discussion the record of the ten studless links made from short bolts, it is found, contrary to the opinion of most makers of chain cables, that, as judged by these samples, the shortening of the links deprived them of all value, for the irregularity of strength displayed is remarkable, and no conclusions based upon any three or four results will stand against the evidence of as many others. *Burned welds* is the only solution which presents itself.

The views of the editor in regard to the preceding tests and the conclusions based upon them having been submitted to the Chief of the Bureau of Equipment, he, in March, 1881, authorized a renewal of the investigation, and a series of experiments was carried on by Commander R. D. Evans, U. S. N., the equipment officer, and by Lieut. John H. Coffin, U. S. N., his assistant.

These were conducted as follows (quoting from the report of Lieutenant Coffin):

"From a large lot of blooms which had been prepared in the usual way for chain-cables twelve were taken at random and rolled into 1⅝″ bars. The fag-ends were cut off, nicked in the center, and bent to right angles, showing good fiber. From each bar six cable bolts were cut, of the usual length, and welded up into two triplets, one triplet studded and one open, the end link being of a larger size. This gave nine triplets of each kind, a studded and unstudded one from each bar, which were welded by the same welder, and made as nearly alike as possible.

Upon test the mean strength of these sections was: 12 studded chains, 144,833 pounds; 12 unstudded chains, 148,333 pounds; the first ranging from 157,000 to 132,000 pounds, the latter from 169,000 to 129,000 pounds.

A second set of tests was made upon another lot of the same iron, but the results, which included breaking strains ranging from 143,000 down to 106,000 pounds, were so very irregular that they were of no value, none of either type going much beyond the minimum of the preceding lot. In every case of very low strength the welds, which were made by one man, were marked "solid," which seems to indicate that with him a solid weld was a burned one.

A third experiment was tried in March, 1881, upon 1¼″ links, prepared and tested as were the other two lots. Twelve triplets of each kind gave results: 9 studded links, 140,378 pounds; 9 unstudded links, 139,756 pounds; the former ranging from 153,000 to 125,600 pounds, the latter from 163,000 to 112,000 pounds.

For the present discussion the strength of the twenty-one sections of each type are arranged as follows:

[Abstract from records of navy-yard, Washington, D. C.]

Competitive tests made upon forty-two sections of three links each, of 1¼″ iron.

[Twenty-one sections each of studded and unstudded links.]

Number of bar.	No. of link sample.	Studded links.		Unstudded links.		Strength.	
		Strength.	Broke at—	Strength.	Broke at—	Stud over no stud.	No stud over stud.
		Pounds.		*Pounds.*		*Pounds.*	*Pounds.*
*250	1	155,000	Qr. W	169,000	Qr. W		14,000
433	2	145,000	... do	138,000	Thro. W	7,000	
*437	3	157,000	....do	129,000	Qr. W	28,000	
*438	4	153,000	....do	136,000	Thro. W	17,000	
424	5	140,000	Thro. W	133,000	....do	7,000	
*235	6	139,000	Qr. W	157,000	....do		18,000
*439	7	133,000	Thro. W	144,000	....do		11,000
237	8	150,000	Qr. W	150,000	Qr. W		
440	9	147,000	....do	145,000	....do	2,000	
*441	10	140,000	....do	161,000	Thro. W		21,000
*442	11	132,000	... do	163,000	....do		31,000
436	12	147,000	....do	155,000	....do		8,000
Average		144,833		148,333			
1	13	130,000	Thro. W	133,600			3,600
*2	14	153,000	Qr. W	135,600		17,400	
3	15	146,000	....do	149,000			3,000
*4	16	152,600	....do	163,000			10,400
4	17	149,600	....do	154,000			4,400
5	18	136,000	....do	143,000			7,000
*5	19	144,600	... do	112,600		31,400	
*6	20	125,600	....do	119,000		7,000	22,400
*3 and 6	21	126,000	No. 6, Thro. W.	148,000			14,000
Average		140,378		139,756			
Total average		142,900		144,610			

Applying to the above tests the same reasoning applied to those of the 1⅝″, we find by table, page 207, that the maximum, average, and minimum strength to be expected of 1¼″ chain is 157,000, 150,500, and 143,000 pounds; and in this case, as with the others, the average of most of the links approximates closely to the latter. And with no other guide we would be justified in declining to incorporate in the means such figures as 169,000 and 112,000; but we have here a simple and reliable indicator as to which links should not be counted, viz, those made from the same bar which differ over 10,000 pounds. Omitting those which are marked (*), the corrected means become, for 9 studded links, 143,330 pounds; 9 unstudded links, 144,510 pounds.

Thus corrected or uncorrected, the evidence given by the 1½″ tests shows that the difference probably due to the effect of the stud is with iron of the ductility of this lot very slight and uncertain, a result which was foreshadowed in the comparison, page 155, which shows that with coarse brittle iron the strength of the unstudded exceeds that of the studded by 15 per cent., a difference which is reduced to 5 per cent. upon more suitable iron.

Summing up the evidence given by this series of tests, we have—

	Pounds.	
Strength of 29 studded 1⅝″	165,680	
Strength of 23 unstudded 1⅝″..........	165,870 =	190 pounds over studded.
Strength of 21 studded 1½″..........	142,290	
Strength of 21 unstudded 1½″..........	144,610 =	2,320 pounds over studded.
Strength of 9 selected studded 1½″.....	143,330	
Strength of 9 selected unstudded 1½″ ..	144,510 =	1,180 pounds over studded.

The difference in each case being in favor of the conclusion that the studded link is not as strong as the unstudded.

Looking over the data, we find that the strongest 1⅝″ section (186,000 pounds) was unstudded, and a second section tied the strongest of the studded links.

With the 1½″ the strongest (169,000 pounds) was unstudded, and three others, viz, (No. 16, 10, and 11,) exceeded the strongest of the studded links (No. 3, 157,000 pounds).

Taken by itself this data would indicate that the links were nearly equal in strength; taken in connection with the previous results, it is strongly confirmatory of the views of the Board, which will therefore be adhered to until disproved.

Desirous of making this record as complete as possible, the editor addressed letters to Mr. Joseph B. Carr, proprietor of the chain factory at Troy, New York, and to Mr. H. L. Fearing, proprietor of the Standard Chain Works at East Bridgewater, Mass., requesting these gentlemen to have tested a few sections of chain cable, similar in all respects, except in the fitting or omission of the stud. Both gentlemen responded favorably, and furnished the results of the tests. .

General Carr made two sections of several links each of 1″ and ⅞″ chain, having half of each studded and half unstudded. Both were pulled asunder, and it was in each case a studded link which parted.

Mr. Fearing prepared six sections of 1⅛″ chain, made of Burden & Sons' chain-iron, three of which were studded and three unstudded. These were broken at the following strains upon his testing machine:

	Studded links.		Unstudded links.
	Pounds.		*Pounds.*
No. 1	83,440	No. 1	90,720
No. 2	85,680	No. 2	91,840
No. 3	86,800	No. 3	92,960
Average..............	85,307	Average..............	91,840

A difference of 6,533 pounds in favor of the *unstudded* links.

Both of the above-named gentlemen are of the opinion that the unstudded is stronger than the studded link.

OTHER SOURCES OF WEAKNESS.

There is still another cause, which does not, however, necessarily always exist, why chain cables do not possess the greatest strength possible for the size, and this is the custom which prevails to a certain extent of purchasing the iron in bolts cut to the length required to make the links. By this system there can be no guarantee to the cable manufacturer that the furnisher of the iron has not mixed with the iron selected, many bolts of inferior and cheaper material, and, perhaps, some of a smaller size than is called for.

We have found that in several lots of iron there were bolts which were evidently of a very different character, and in many cases bolts from one to four hundredths of an inch scant. This deficiency in size becomes of importance when the bolt is transformed to a link, as may be shown thus:

Bar 2″ diameter, tensile strength 52,000 pounds per square inch, strength of link 266,281 pounds.

Bar 1.96″ diameter, tensile strength 52,000 pounds per square inch, strength of link 255,710 pounds.

Assuming that in each case the link was equal to 163 per cent. of the bar's strength.

The risk from this cause naturally depends, to a great extent, upon the character of the persons who furnish and of those who manufacture the iron, and upon the degree of care which is exercised at the mills. We have shown that deficiency in welding properties stands first, and the action of the stud second in the list of causes which prevents the cable-link from developing the full strength of twice that of the bar.

Our experiments indicate that the former cause is frequently manifested by the tenacity of the bar; if the tensile strength is high, its excess is probably due either to chemical constituents, which increase tenacity at the expense of welding properties, or to excessive work, of which the tendency is to effect the same, the amount of work which would be excessive varying with the nature of the material.

The effect of the former source is fully discussed in the comparison of chemical and physical results; that of the latter has been made very evident throughout our experiments. A few typical examples will be given in which the variation in the welding value was apparently due to variations in the amount of work, the irons being of similar composition.

In case of irons F and F*x*, both were of the same material, F*x* receiving, however, much more work than F, the piles from which the bars were rolled being larger. F*x* exceeded in tenacity, was equal if not superior in power to resist sudden strain, and ductility, but inferior as cable, on account of decreased welding value. Iron F*x* developed in the link form an average of 154 per cent. of the bar's strength, and iron F over 163 per cent. of the same.

With irons F, F*x*, O, and P, all of which were of choice, ductile material, the small bars, which had received the most work, made the poorest cable.

With irons A, N, B, C, which were made from comparatively coarse material, the effect of increased work was to improve them in every respect, the smaller and most thoroughly worked sizes making the best cable. With N, for instance, the 1⅝″ thoroughly worked, in comparison with the 2″, developed 164 per cent. of bar strength, while the 2″ developed but 141 per cent. With B the $1\frac{3}{16}$″, developed 162 per cent. and the $1\frac{7}{16}$″, more worked, $176\frac{1}{2}$ per cent. With C the $1\frac{3}{4}$″ developed 153 per cent. and the $1\frac{1}{2}$″, 162 per cent. With all of these irons the tenacity of the small was higher than that of the larger bars. The question, therefore, as to the amount of tenacity which indicates deficiency in welding value is one which is dependent, to a great extent, upon the character of the material. The amount which indicates a probable lack of power to resist sudden strains also depends greatly upon the same. Iron F*x*, with greater tenacity than F, was equally valuable in this respect, as were A, D, and P*x*.

But there is another element which complicates this question: the amount of tenacity which indicates probable high or low welding value and ductility depends in the same material to a great extent upon the diameter of the bar, and differs with every variation in size. The problem thus became to fix upon the tenacity which upon each size of bar used ordinarily for cables indicates probable high welding value and freedom from brittleness.

The history of our efforts to solve this problem, with such solution as we have found, is embodied in the papers "Investigation of the effect of the rolls," and "Proving-strains for chain-cables."

The facts upon which our theories are based are the strength, elastic limit, and resilience of bars, already given, the same of links, and the comparison of the strength, &c., of both, which will be here inserted.

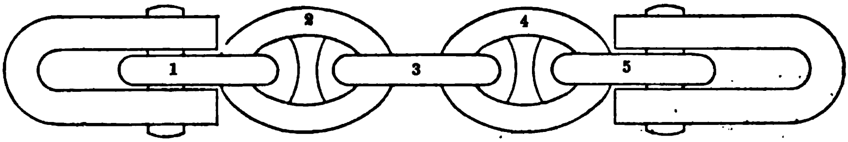
Detailed description of method of testing cables.

Our records embrace the results of strength, &c., obtained by the rupture of 229 sections of cables, of various diameters and lengths, made from eighteen different irons.

These are given in the tabulated record of breaking strains, arranged in the order of the relative strength.

The history of a few of our tests will be given in detail.

The links were generally arranged as shown in the cut—the end links, Nos. 1 and 5, and center link, No. 3, being unstudded, the others studded. The end links were in some cases of greater diameter than the links to be tested, in which case they were not recorded in the number of links in section.



After we had decided upon the superior strength of the unstudded link, our test-sections were prepared with end links of the same size and iron as the other links, but without studs; and in breaking over 400 sections thus arranged the end link broke in but eight cases.

The shackle-pins were oval, and made to correspond with the diameter of the links.

Test as cable, of iron Fx.

[Links arranged as per cut. Stretch recorded, when .03 was observed, on No. 2 link.]

Diameter of iron.	Number of links.	Stress at first stretch.	Elongation of—			Stress at rupture.	Number of link which broke.	Location of rupture.	Elongation of unbroken links.		
			No. 2.	No. 3.	No. 4.				No. 2.	No. 3.	No. 4.
"		*Pounds.*	"	"	"	*Pounds.*			"	"	"
1	3	34,800	.03	.11	.03	70,300	4	Q. W.	.50	.62	....
1⅛	3	44,400	.03	.16	.03	81,400	2	T. W.	....	.70	.72
1¼	3	61,100	.03	.14	.05	111,000	2	Q. B.	....	1.00	.70
1⅜	3	78,000	.05	.24	.03	124,000	3	W.	1.45	....	.75
1½	3	80,000	.03	.28	.04	153,000	2	Q. W.	....	1.15	1.00
1⅝	3	98,000	.03	.28	.06	168,000	2	Q. W.	....	1.35	1.25
1¾	3	100,000	.03	.26	.04	185,000	2	Q. W.	....	1.20	1.40
1⅞	3	110,000	.03	.22	.03	205,600	3	T. W.	1.60	....	1.30
2	3	117,200	.03	.19	.04	240,000*	......	....	1.50	1.70	1.60

* Not broken.

Five ruptures occurring on link No. 2, one on No. 4 studded, and two on open links, in one of which the weld drew. The elongation produced upon the open links by the stress which broke the studded ones was not sufficient to greatly impair their usefulness; the 1", with original inner diameter of 1.55", being reduced to 1.40"; the 1⅞", original inner diameter 2.8", after stress 2.50", and the others in proportion, there being sufficient room for the links to traverse freely.

Test as cable, of iron D.

[Links arranged as per cut. Results as follows:]

Size of link.	Number of links.	Stress at first stretch.	Elongation of—			Stress at rupture.	Link which broke.	Location of rupture.	Elongation of unbroken links.		
			No. 2.	No. 3.	No. 4.				No. 2.	No. 3.	No. 4.
"		*Pounds.*	"	"	"	*Pounds.*			"	"	"
1	3	36,200	.03	.10	.04	79,200	2	Q. W.	....	.50	.75
1⅛	3	45,000	.03	.15	.03	87,500	2	Q. W.	....	.75	.80
1¼	3	55,200	.03	.20	.05	113,000	2	Q. W.	....	.80	.80
1⅜	3	71,500	.03	.26	.04	137,200	2	Q. W.	....	1.00	1.25
1½	3	80,100	.03	.30	.03	173,000	4	Q. W.	1.00	1.50	....
1⅝	3	90,000	.03	.25	.04	182,000	2	Q. W.	....	1.80	1.20
1¾	3	99,000	.03	.24	Lost.	204,000	4	Q. W.	1.70	1.40	....
1⅞	3	112,300	.03	.32	.03	215,000	4	T. W.	2.00	1.75	....
2	3	116,000	.03	.22	.05	240,000*	......	....	1.55	1.70	1.40

* Not broken.

Eight ruptures occurred on studded links, five of which were on No. 2. Nearly all of the unbroken open links were serviceable after rupture of the studded ones.

Tests as cable of iron O.

[Links arranged as per cut; results as follows:]

Diameter of iron.	Number of links.	Stress at first stretch.	Elongation of—			Stress at rupture.	Link which broke.	Location of rupture.	Elongation of unbroken links.		
			No. 2.	No. 3.	No. 4.				No. 2.	No. 3.	No. 4.
"		*Pounds.*	"	"	"	*Pounds.*			"	"	"
1	3	31,400	.03	.23	.03	68,000	4	Q. W.	.66	1.00	....
1⅛	3	85,000	.02	.16	.08	80,900	2	Q. W.	....	.63	.53
1¼	3	45,800	.05	.22	.03	95,500	3	T. W.	.56	....	.40
1⅜	3	51,200	.04	.20	.03	125,400	2	Q. W.	....	.90	.60
1½	3	60,000	.04	.14	.03	155,500	2	Q. B.	....	1.32	1.60
1⅝	3	74,500	.03	.15	.08	180,000	2	Q. W.	....	1.32	1.50
1¾	3	90,000	.02	.25	.03	207,000	2	Q. W.	....	1.50	1.40
1⅞	3	102,000	.03	.22	.03	237,000	4	Q. B.	1.80	2.00	....
2	3	119,800	.02	.20	.03	238,000	2	Weld.	....	.40	.503

Six of the ruptures occurred on No. 2 link, two on No. 4, and one on No. 3. The weld of the 2″ drew and it broke much under its real strength, as is shown by the slight elongation.

It is probable that so very ductile and expensive an iron as O, which is first-class charcoal blown, will seldom be made into chains, hence we reason that as some of the open links were serviceable after the rupture of the studded ones, that we are furnished with their comparative value. With a harder iron the elongation would have been less.

Tests as cable of iron N.

We, having but a small quantity of this iron, were not able to arrange the links in the same manner as with the preceding tests. They were arranged thus: No. 1, open; Nos. 2 and 3, studded; No. 4, open.

The results of the tests were:

Size of iron.	Number of links.	Stress at first stretch.	Elongation of—				Stress at rupture.	Link which broke.	Location of rupture.	Elongation of unbroken links.			
			No. 1.	No. 2.	No. 3.	No. 4.				No. 1.	No. 2.	No. 3.	No. 4.
"		*Pounds.*	"	"	"	"	*Pounds.*			"	"	"	"
1⅛	4	45,000	.06	.08	.03	.11	85,000	2	T. W.	.53	......	.73	.50
1¼	4	58,000	.08	.03	.05	.09	105,000	2	Q. W.	.62	......	.80	64
1⅜	4	70,100	.06	.03	.03	.10	126,400	4	Q. W.	.82	.82	.88	......
1½	4	80,000	.09	.03	.02	.07	152,200	4	Q. W.	.90	1.00	.87	......
1⅝	4	96,200	.05	.02	.03	.08	195,500	2	Q. W.	1.10	......	1.00	1.50
1¾	4	110,300	.10	.03	.04	.06	201,100	2	Q. W.	.65	......	.60	.50
1⅞	4	116,200	.11	.04	.03	.12	223,700	2	Q. W.	1.12	......	1.38	.90
2	4	118,000	.07	.03	.04	.08	232,000	2	T. W.	.67	......	.90	1.03

Six of the ruptures occurred upon No. 2 link, all upon studded links, and at the stress at which they yielded *all* of the open links were serviceable.

This is a hard, coarse, common chain-iron.

These carefully made tests indicate that, with ordinary chain iron, although the first stretch of the open link is produced by a much lower stress than that which the studded one withstands, yet, upon the strain becoming more severe, the disproportion in its effects becomes less, and that frequently the open link is still serviceable after the studded link has broken.

A curious phenomenon was noticed during these tests. In breaking 33 sections, made from four irons, 22 of the ruptures occurred upon No. 2 link.

In each case there was no known difference in the strength of the different links; and we can only attribute the frequency of this rupture to the location of the link, and in so doing we recognize that the action of the testing-machine is *not* that of steady tension, as we had hitherto assumed, but of a series of rapid pulsations.

No. 2 link was in each case the nearest studded link to the engine by which the force was developed, and a theory suggests itself by which the phenomenon may be explained.

The tension is produced by strokes of a hydraulic pump; between these strokes the chain is strained by the amount already accumulated, and this strain is increased, not gradually, but by a succession of sharp strokes, the effect of which is probably as follows: At the beginning, as the stress becomes equal to the elastic limit of No. 1 link, which is not studded, the sides slowly close, and thus a portion of the force is absorbed, and No. 2 link does not receive so great a strain as No. 1 has before another stroke increases that upon the latter.

When the stress becomes so great that No. 1 has closed so much that nearly as much is required to further close it as to break it, the stress is applied at once to No. 2 with slight reduction.

No. 2 receives this stress as a sudden strain; but by the mass of its material and its inertia transmits it to Nos. 3 and 4 as a nearly steady strain, No. 2 acting toward Nos. 3 and 4 as does the anvil on the breast of an athlete, and absorbing the blow. Finally, No. 2 receives a stroke which breaks it before it has time to transmit to No. 3. If this is not the cause of the phenomenon, we are unable to assign one.

The following records were obtained in the manner described:

Breaking-strains of 229 sections of links of various irons.

Number.	Size.	Number of links in test-section.	Breaking-strain.	Where broken.	Iron.	Number.	Size.	Number of links in test-section.	Breaking-strain.	Where broken.	Iron.
	In.		*Pounds.*				*In.*		*Pounds.*		
1	1	5	79,200	Qr. W	D.	13	1¼	2	110,800	W	A.
2		2	73,632	Qr. B	A.	14		3	107,600	Thro. B	F.
3		2	72,672	do	A.	15		3	105,000	Qr. W	N.
4		2	71,712	do	A.	16		3	102,000	W	M.
5		3	70,300	Qr. W	Fx.	17		2	101,700	Qr. W	F.
6		5	69,600	do	A.	18		3	101,000	W	M.
7		3	68,000	Thro. B	O.	19		2	96,000	do	K.
8		3	67,600	Thro. W	F.	20		3	95,500	Thro. W	O.
9		3	60,400	Thro. B	P.	21		3	92,000	do	M.
1	1⅛	3	89,280	Qr. B	A.	1	1$\frac{5}{16}$	3	117,000	Qr. W	M.
2		2	88,800	Qr. W	A.	2		3	115,000	Thro. W	M.
3		3	87,500	do	D.	3		3	111,500	Qr. W	P.
4		2	86,400	do	F.	4		3	110,500	Qr. B	P.
5		3	85,000	Thro. W	F.	5		3	110,000	Thro. B	P.
6		3	85,000	do	N.	6		3	109,500	do	P.
7		2	84,500	Qr. W	K.	7		3	109,500	Qr. W	P.
8		3	81,400	Thro. W	Fx.	8		3	109,000	do	P.
9		3	80,900	Qr. W	O.	9		3	92,000	Thro. W	M.
10		3	76,000	do	P.	10		3	77,000	do	M.
1	1¼	3	123,500	Qr. B	M.	1	1⅜	3	137,200	Qr. W	D.
2		3	122,100	Thro. W	P.	2		3	136,600	Thro. W	M.
3		3	119,800	Qr. W	M.	3		3	136,320	Qr. B	A.
4		3	119,500	do	M.	4		2	134,592	Qr. W	P.
5		3	119,000	B	M.	5		3	133,000	do	M.
6		3	118,480	Qr. W	A.	6		2	132,480	Qr. B	A.
7		3	114,000	do	M.	7		3	132,000	Thro. W	M.
8		3	113,000	do	D.	8		3	128,600	Thro. B	F.
9		3	112,500	B	M.	9		3	127,600	Thro. W	M.
10		3	112,000	do	M.	10		3	126,800	do	M.
11		3	112,000	Qr. W	M.	11		3	126,600	do	M.
12		3	111,000	Qr. B	Fx.	12		4	126,400	Qr. W	N.

Breaking-strains of 229 sections of links of various irons—Continued.

Number.	Size.	Number of links in test-section.	Breaking-strain.	Where broken.	Iron.	Number.	Size.	Number of links in test-section.	Breaking-strain.	Where broken.	Iron.
	In.		*Pounds.*				*In.*		*Pounds.*		
13	1⅜	3	120,000	Qr. B	M.	1	1⅝	3	199,000	Qr. B	P.
14		3	125,800	Qr. W	K.	2		3	195,500	Qr. W	N.
15		3	125,000	do	O.	3		5	194,900	do	C.
16		3	125,000	Qr. B	M.	4		10	188,200	Qr. B	C.
17		3	124,000	W	Fx.	5		3	187,000	Qr. W	M.
18		3	122,500	Qr. B	M.	6		2	185,300	Qr. B	C.
19		3	122,000	Qr. W	M.	7		2	184,900	do	C.
20		3	121,000	Qr. B	M.	8		2	183,900	Qr. W	K.
21		3	120,500	Qr. W	M.	9		3	182,000	do	D.
22		3	119,000	Thro. W	M.	10		3	180,000	do	O.
23		2	119,000	Qr. W	F.	11		3	180,000	Thro. W	M.
24		3	118,400	do	P.	12		3	179,000	do	A.
25		3	115,600	Thro. W	M.	13		7	177,100	Qr. W	C.
26		3	115,000	do	M.	14		2	174,700	Qr. B	F.
27		3	113,000	do	M.	15		3	174,700	Qr. W	C.
28		3	111,000	do	M.	16		2	171,000	do	K.
29		3	111,000	do	M.	17		2	169,000	Side	A.
30		3	106,000	do	M.	18		3	168,000	Qr. W	Fx.
31		3	105,800	do	M.	19		3	125,000	Thro. W	M.
32		3	103,400	do	M.						
33		3	96,000	do	M.	1	1 11/16	2	214,160	Qr. W	B.
34		3	95,800	do	M.	2		3	207,000	Thro. W	M.
35		3	95,000	do	M.	3		3	204,480	Qr. W	B.
						4		2	204,480	do	B.
1	1 7/16	2	155,040	Qr. W	B.	5		2	202,560	do	B.
2		2	154,750	do	B.	6		5	201,020	do	B.
3		2	154,000	do	B.	7		2	199,680	do	B.
4		5	153,400	Thro. W	B.	8		2	198,700	do	B.
5		2	152,600	do	B.	9		2	196,990	do	B.
6		2	152,000	do	B.	10		5	196,800	do	B.
7		2	151,700	do	B.	11		7	195,800	do	B.
8		2	150,700	Qr. W	B.	12		2	194,880	do	B.
9		2	150,000	Thro. W	B.						
10		2	149,000	Qr. B	B.	1	1¾	2	231,300	Qr. W	C.
11		2	144,480	Qr. W	B.	2		2	225,600	Qr. B	C.
12		3	142,500	Qr. B	P.	3		3	225 600	Qr. W	M.
13		3	141,200	do	P.	4		3	223,000	B	M.
14		3	141,000	do	P.	5		2	216,000	Qr. W	A.
15		3	141,000	do	P.	6		3	215,600	Qr. B	M.
16		3	140,900	do	P.	7		3	213,000	Qr. W	A.
17		2	140,000	Thro. W	B.	8		3	213,000	do	M.
18		2	139,600	do	B.	9		7	212,200	Qr. B	C.
19		3	139,400	Qr. B	P.	10		3	212,000	Thro. W	M.
						11		3	212,000	Thro. B	P.
1	1½	3	173,000	Qr. W	D.	12		3	207,400	W	C.
2		3	169,000	Thro. W	M.	13		3	207,000	Qr. W	O.
3		7	163,700	B	C.	14		3	204,000	do	D.
4		2	162,800	do	C.	15		2	203,500	do	F.
5		3	162,000	Thro. W	M.	16		10	203,500	do	C.
6		3	161,000	do	M.	17		10	202,600	do	C.
7		3	160,300	Qr. W	C.	18		3	201,100	do	N.
8		2	159,400	do	A.	19		3	197,600	do	F.
9		3	159,400	B	C.	20		5	196,800	W	C.
10		3	158,600	Qr. W	M.	21		3	195,800	do	C.
11		3	158,000	Thro. W	M.	22		5	193,000	Qr. W	C.
12		10	157,000	Qr. B	C.	23		7	192,000	do	C.
13		3	156,000	Qr. W	P.	24		10	191,000	do	C.
14		3	155,600	Thro. W	M.	25		3	185,500	do	Fx.
15		3	155,600	Qr. W	M.						
16		3	155,500	do	O.	1	1 13/16	2	231,940	Qr. W	B.
17		3	155,500	Butt	F.	2		2	230,590	do	B.
18		10	155,100	B	C.	3		3	228,600	Thro. W	M.
19		3	155,000	Thro. W	M.	4		3	228,600	Qr. W	B.
20		3	153,000	Qr. W	Fx.	5		7	224,700	do	B.
21		4	152,200	do	N.	6		3	222,000	Thro. W	M.
22		3	152,000	Thro. W	M.	7		3	222,000	do	M.
23		3	151,600	do	M.	8		2	212,700	Qr. W	B.
24		3	151,000	do	M.	9		5	211,390	do	B.
25		3	150,500	W	F.	10		3	210,000	Thro. W	M.
26		2	147,840	Side	A.	11		5	204,400	Qr. W	B.
27		5	147,000	Qr. W	C.						
28		3	143,900	Thro. W	M.	1	1⅞	2	252,960	Side	A.
29		2	143,000	Qr. W	K.	2		3	237,000	Qr. B	O.
30		3	140,000	Thro. W	M.	3		3	233,000	do	P.
31		2	134,592	Qr. W	P.	4		2	230,900	Qr. W	F.

Breaking-strains of 229 sections of links of various irons—Continued.

Number.	Size.	Number of links in test-section.	Breaking-strain.	Where broken.	Iron.	Number.	Size.	Number of links in test-section.	Breaking-strain.	Where broken.	Iron.
	In.		*Pounds.*				*In.*		*Pounds.*		
5	1⅞	3	223,700	Qr. W	N.	17	2	3	238,000	W	O.
6		3	215,600	Thro. W	F.	18		2	233,600	Thro. W	F.
7		3	215,000	do	D.	19		2	232,000	do	N.
8		3	205,600	do	Fx.						
1	2	2	283,200	Qr. B	A.		2	3	242,000	Not broken	P.
2		2	279,9.6	Thro. B	A.			3	240,000	do	D.
3		3	278,000	Qr. B	M.			3	240,000	do	Fx.
4		3	278,000	Side	M.			2	240,000	do	A.
5		3	276,000	Qr. W	M.						
6		2	270,240	Qr. B	A.		1¼	4	116,000	Thro. W	Px.
7		2	269,000	do	A.						
8		2	268,800	Not broke	A.		1⅜	4	156,000	do	Px.
9		2	268,750	Qr. W	F.						
10		2	268,224	do	A.		1⅝	3	196,200	Qr. B	Px.
11		2	260,832	do	A.						
12		2	258,900	do	K.		1¾	3	209,800	Qr. W	Px.
13		2	257,260	Qr. B	A.						
14		3	255,000	Side	M.		1⅞	2	236,000	Thro. W	Px.
15		2	248,000	Qr. B	A.						
16		2	244,000	Thro. B	A.		2	2	242,000	Not broken	Px.

Breaking-strain of 206 single links.

Number.	Size.	Number of links in test-section.	Breaking-strain.	Where broken.	Iron.	Number.	Size.	Number of links in test-section.	Breaking-strain.	Where broken.	Iron.
1	1	1	76,320	Qr. B	A.	1	1⅜	1	144,800	Qr. W	D.
2		1	75,968	Side	A.	2		1	142,000	Side	D.
						3		1	141,000	Thro. W	M.
1	1⅛	1	101,800	Thro. W	C.	4		1	139,600	do	M.
2		1	100,400	Qr. W	K.	5		1	139,500	Qr. W	M.
3		1	97,900	do	F.	6		1	139,200	do	E.
4		1	97,400	Butt	D.	7		......	137,700	do	E.
5		1	96,600	Qr. B	A.	8		......	137,200	Qr. B	K.
6		1	95,000	Qr. W	D.	9		......	136,800	Qr. W	F.
7		1	94,100	do	F.	10		......	136,000	Thro. W	M.
8		1	94,080	Qr. B	A.	11		......	135,600	do	M.
9		1	92,200	Qr. W	K.	12		......	135,400	Qr. B	F.
10		1	90,200	do	E.	13		......	135,000	Qr. W	M.
11		1	87,500	do	E.	14		......	134,880	do	A.
12		1	87,400	do	E.	15		......	134,800	do	C.
13		1	85,500	do	E.	16		......	134,400	W	M.
						17		......	133,500	Qr. W	M.
1	1¼	1	128,832	Qr. W	P.	18		......	133,000	Thro. W	M.
2		1	128,600	do	K.	19		......	132,600	Qr. W	E.
3		1	125,500	Qr. B	M.	20		......	132,000	do	C.
4		1	124,800	Qr. W	M.	21		......	130,100	do	E.
5		1	124,800	do	D.	22		......	130,000	do	M.
6		1	124,800	Side	C.	23		......	127,600	do	M.
7		1	123,800	Qr. W	K.	24		......	126,700	Side	K.
8		1	123,500	Qr. B	M.	25		......	125,600	Thro. W	M.
9		1	122,800	Qr. W	D.	26		......	116,000	do	M.
10		1	122,100	do	C.	27		......	115,000	do	M.
11		1	122,000	do	M.	28		1	113,300	do	M.
12		1	121,000	Thro. B	M.	29		1	113,000	Side	M.
13		1	119,000	Qr. B	E.	30		1	112,100	Thro. W	M.
14		1	115,800	Thro. W	M.	31		1	105,000	do	M.
15		1	115,200	Qr. W	F.						
16		1	113,700	do	E.						
17		1	113,300	Qr. B	F.						
18		1	112,500	do	E.	1	1$\frac{7}{16}$	1	178,000	Qr. W	K.
19		1	111,360	Qr. W	A.	2		1	162,432	Qr. B	E.
20		1	111,000	Thro. W	M.	3		1	162,050	Qr. W	B.
21		1	110,400	E. lk	M.	4		1	155,500	do	P.
22		1	109,400	Qr. W	E.	5		1	155,100	do	G.
						6		1	153,600	do	J.
1	1$\frac{5}{16}$	1	133,000	Thro. W	M.	7		1	153,500	do	P.
2		1	130,000	do	M.	8		1	153,020	do	B.
3		1	128,000	do	M.	9		1	150,530	do	B.
4		1	123,000	Qr. B	P.	10		1	149,760	do	B.
5		1	121,800	do	P.	11		1	149,600	do	C.
6		1	113,400	Qr. W	P.	12		1	139,400	Thro. W	P.
7		1	110,000	Thro. W	M.	13		1	138,600	do	L.

Breaking-strain of 206 *single links*—Continued.

Number.	Size.	Number of links in test-section.	Breaking-strain.	Where broken.	Iron.	Number.	Size.	Number of links in test-section.	Breaking-strain.	Where broken.	Iron.
	In.		*Pounds.*				*In.*		*Pounds.*		
1	1½	1	193,200	Thro. W	L.	3	1 11/16	1	221,950	Qr. W	B.
2		1	184,700	Qr. W	K.	4		1	219,300	Qr B	K.
3		1	179,520	... do	E.	5		1	213,696	do	E.
4		1	178,500	Side	D.	6		1	213,120	Qr. W	B.
5		1	178,200	Qr. W	C.	7		1	211,600	....do	J.
6		1	178,100	....do	D.	8		1	207,000	T. W	M.
7		1	176,300	Side	C.	9		1	203,140	Qr. W	B.
8		1	174,700	Qr. W	C.	10		1	198,000	....do	G.
9		1	174,000	E. lk	M.	11		1	197,800	....do	C.
10		1	173,700	Qr. W	C.						
11		1	173,000	... do	M.	1	1¾	1	256,300	Qr. W	C.
12		1	171,800	... do	C.	2		1	254,600	....do	L.
13		1	170,000	... do	H.	3		1	241,500	....do	K.
14		1	168,960	Side	C.	4		1	241,000	....do	C.
15		1	168,600	Qr. W	M.	5		1	237,100	... do	C.
16		1	167,000	Side	C.	6		1	235,600	... do	M.
17		1	166,560	....do	C.	7		1	235,000	Thro. W	M.
18		1	165,600	... do	C.	8		1	232,300	Qr. W	C.
19		1	165,600	Qr. B	M.	9		1	231,400	... do	D.
20		1	165,600	Thro. W	M.	10		1	228,500	....do	C.
21		1	164,640	Qr. B	C.	11		1	226,500	... do	C.
22		1	163,680	W	C.	12		1	225,200	....do	H.
23		1	162,400	Qr. W	E.	13		1	222,700	... do	J.
24		1	161,000	Thro. W	M.	14		1	221,500	....do	E.
25		1	160,100	Qr. W	G.	15		1	218,304	Qr. B	E.
26		1	158,900	....do	E.	16		1	215,520	... do	A.
27		1	158,400	....do	A.	17		1	215,200	Qr. W	G.
28		1	157,600	....do	J.	18		1	210,200	....do	F.
29		1	155,600	Thro. W	M.	19		1	200,600	Qr. B	C.
30		1	153,000	....do	M.	20		1	200,000	Thro. W	M.
31		1	152,600	Thro. B	F.	21		1	198,600	....do	M.
32		1	147,600	Qr. W	M.	22		1	193,000	....do	M.
33		1	146,900	....do	K.						
						1	1 13/16	1	249,000	Thro. W	M.
1	1⅝	1	215,400	Qr. W	K.	2		1	243,000	do	M.
2		1	205,056	Qr. B	E.	3		1	240,770	Qr. W	B.
3		1	204,100	....do	H.	4		1	239,420	... do	B.
4		1	203,500	Qr. W	C.	5		1	234,816	Qr. B	E.
5		1	202,200	....do	K.	6		1	234,050	....do	B.
6		1	199,700	....do	D.	7		1	233,280	Qr. W	B.
7		1	199,300	Qr. B	C.	8		1	232,000	... do	L.
8		1	197,800	Qr. W	C.	9		1	228,860	Qr. B	B.
9		1	195,200	E. lk	G.	10		1	227,300	Qr. W	C.
10		1	194,300	Qr. W	E.	11		1	225,600	Thro. W	M.
11		1	193,000	....do	M.	12		1	225,220	Qr. W	B.
12		1	192,900	....do	C.	13		1	223,300	... do	G.
13		1	190,100	....do	C.	14		1	219,260	do	B.
14		1	189,100	....do	F.	15		1	210,000	Thro. W	M.
15		1	186,800	....do	C.	16		1	210,000	....do	M.
16		1	185,300	....do	E.	17		1	195,800	Qr. W	J.
17		1	184,800	....do	A.						
18		1	182,500	....do	M.	1	1⅞	1	264,000	Qr. B	K.
19		1	178,600	... do	C.	2		1	263,000	... do	K.
20		1	175,000	Thro. W	M.	3		1	252 480	Side	A.
21		1	173,000	....do	M.	4		1	243,600	Qr. W	E.
22		1	163,600	Qr. W	L.	5		1	238,100	....do	D.
23		1	163,200	... do	K.	6		1	223,600	....do	E.
24		1	135,000	Thro. W	M.	7		1	223,200	....do	F.
25		1	120,000	....do	M.						
						1	2	1	293,760	Thro. B	A.
1	1 11/16	1	233,800	Qr. W	K.	2		1	278,000	Qr. B	M.
2		1	222,900	....do	L.	3		1	276,500	Qr. W	D.

The bars of P*x* were received and tested subsequent to the completion of the tables, and are not included in the following abstract; by which it appears that a variation of from 5 to 17 per cent. in the strength of chain-cables of the same diameter may be expected, when made from good iron, and that this variation may rise to over 25 per cent., if inferior material is used.

Variation in strength of chain-cables made from irons of different character.

Size of cable.	Number of tests.	Number of irons represented.	Strength of cable.		Variation in strength.		Weak links omitted of irons.	Variation in strength by including omitted links.	
			Maximum.	Minimum.	Pounds.	Per cent. of maximum.		Pounds.	Per cent.
In.			*Pounds.*	*Pounds.*					
1	9	6	79. 200	67, 600	11, 600	14	P.	18, 800	23. 7
$1\frac{1}{8}$	10	7	89, 280	80, 900	8, 380	9. 4	P.	13, 200	14. 7
$1\frac{1}{4}$	21	7	122, 100	101, 700	20, 400	16. 6	K, M, O.	31, 100	25
$1\frac{5}{16}$	10	1	115, 000	109, 000	6, 000	5	M.	40, 000	34. 7
$1\frac{3}{8}$	35	9	137, 200	125, 000	12, 200	8	M, Fx.	42, 200	30. 7
$1\frac{7}{16}$	19	2	155, 040	139, 400	15, 640	10	....	....	......
$1\frac{1}{2}$	31	9	173, 000	147, 000	26, 000	15	M, K, P.	38, 400	22. 2
$1\frac{5}{8}$	19	12	199, 000	168, 000	31, 000	15. 5	M.	74, 000	37
$1\frac{11}{16}$	12	2	214, 160	194, 880	19, 280	9	....	....	......
$1\frac{3}{4}$	25	8	231, 300	191, 000	40, 300	17	Fx.	45, 800	19. 7
$1\frac{13}{16}$	11	2	231, 940	204, 400	27, 540	12	....	....	......
$1\frac{7}{8}$	8	6	252, 960	215, 000	37, 960	11	Fx.	47, 360	18. 6
2	19	8	283, 200	240, 000	43, 200	15	....	....	......
	229	.....	....	....	....	12. 1	....	....	25. 1

The excessive variation in case of the 1¾″ is due to the fact that a portion of a lot of excellent chain-iron C was composed of very inferior material, which was very irregular in strength, the strongest link in the lot breaking at 231,300 pounds, and five out of eleven sections breaking at less than 200,000 pounds; the minimum being that in the table, 191,000 pounds.

No system of tests made upon cable-bolts alone would have detected with certainty this inferior iron. Had the iron been furnished in 30-feet bars, each bar would have produced 16 bolts, with a remainder of 24″ for test purposes, the test of which would have given valuable evidence of the character of the 16 links.

WEIGHT OF CHAIN-CABLES.

The chain-cables manufactured by the ordinary systems are very heavy, and we are led by the results of our investigation to believe that their weight can be reduced advantageously, and as great, if not greater, safety be secured.

If this result can be accomplished, it would prove of great value to the mercantile marine, where as much space and tonnage as possible are required for cargo, and where vessels are frequently short-handed.

Two methods present themselves as results of our experiments, the first founded upon our investigation of the action of the rolls and our impact-tests combined, and the second upon our comparative experiments of the strength of studded and open links.

The weight and dimensions of the various portions of cables of different sizes, and of full cables, of the length ordinarily used, are given in the following table:

Number and weight of links in 150 fathoms, dimensions and weight of cable-bolts and finished links, with the weights of swivels, shackles, and club-links.

	Number of links in 150 fathoms.	Weight of links in 150 fathoms.		Cable-bolts.		Weight of studs.	Finished links.			Weight of—			Number of links in fathom.	Total weight of 150 fathoms cable.	
		Studded.	Unstudded.	Length.	Weight.		Length.	Width.	Weight.	Swivel.	Shackle.	Club-link.		Studded link.	Unstudded link.
		Lbs.	*Lbs.*	*In.*	*Lbs.*	*Lbs.*	*In.*	*In.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*		*Lbs.*	*Lbs.*
1...	2,925	8,482	7,751	12	2.65	.25	5 11/16	3 9/16	2.90	17	6.5	50	19½	8,665	7,934
1 1/16.	2,775	9,518	8,825	12¾	3.18	.25	6 1/16	3 11/16	3.43	17	6.5	50	18½	9,701	9,008
1⅛..	2,700	11,394	10,206	13½	3.78	.44	6 4/16	4	4.22	21	9	82	18	11,650	10,462
1 3/16.	2,550	12,470	11,348	14¼	4.45	.44	6 12/16	4 3/16	4.89	21	9	82	17	12,726	11,604
1¼..	2,450	13,916	12,691	15	5.18	.50	7	4 7/16	5.68	26	12	96	16	14,236	13,020
1 5/16.	2,325	15,113	13,950	15¾	6.00	.50	7 5/16	4 9/16	6.50	26	12	96	15½	15,442	14,279
1⅜..	2,250	16,920	15,525	16½	6.90	.62	7 8/16	4 13/16	7.52	30	15.5	131	15	17,326	15,931
1 7/16.	2,100	17,850	16,548	17¼	7.88	.62	8	5 1/16	8.50	30	15.5	131	14	18,256	16,954
1½..	2,025	19,643	18,124	18	8.95	.75	8 4/16	5 7/16	9.70	35	19.5	165	13½	20,143	18,624
1 9/16.	1,950	21,197	19,734	18¾	10.12	.75	8 11/16	5 9/16	10.87	35	19.5	165	13	21,697	20,234
1⅝..	1,875	23,344	21,356	19½	11.39	1.06	9	5 13/16	12.45	48	24	220	12½	23,996	22,008
1 11/16.	1,800	24,858	22,950	20¼	12.75	1.06	9 6/16	6	13.81	48	24	220	12	25,510	23,602
1¾..	1,725	26,686	24,530	21	14.22	1.25	9 12/16	6 5/16	15.47	62	29	262	11½	27,480	25,330
1 13/16.	1,650	28,133	26,070	21¾	15.80	1.25	10 2/16	6 7/16	17.05	62	29	262	11	28,933	26,870
1⅞..	1,650	31,350	28,875	22½	17.50	1.50	10 5/16	6 12/16	19	75	34.5	339	11	32,334	29,859
1 15/16	1,575	32,760	30,398	23¼	19.30	1.50	10 12/16	6 14/16	20.80	75	34.5	339	10½	33,744	31,382
2...	1,500	34,980	31,845	24	21.23	2.09	10 14/16	7 4/16	23.32	95	40.5	360	10	36,125	32,900
2 1/16.	1,500	38,070	34,935	24¾	23.29	2.09	11 5/16	7 9/16	25.38	95	40.5	360	10	39,215	36,080
2⅛..	1,425	39,501	36,295	25½	25.47	2.25	11 12/16	7 12/16	27.72	1.15	47	380	9½	40,811	37,605
2 3/16.	1,350	40,554	37,517	26¼	27.79	2.25	12 2/16	7 12/16	30.04	1.15	47	380	9	41,864	38,827

The first, third, sixth, ninth, and twelfth stretches have each a swivel placed in the center of them.
The weight of the bolts is based on an estimate allowing .2816 pound to cubic inch.

FIRST METHOD BY WHICH THE WEIGHT CAN BE REDUCED TO A GREATER PROPORTIONAL EXTENT THAN THE STRENGTH.

We have found that when made from the same material the large bars possess less strength in proportion to their areas than the small ones, as opposed to steady strain, and generally much less absolute power to resist sudden strains, and in connection, that through the greater amount of work which it receives, the bar of 1⅝″ diameter is, upon an average, fully 4,000 pounds per square inch stronger than the 2″ bar. This difference of 4,000 pounds we derive from the following data: With the irons A, D, D (second lot), E (1½″), F (two lots), N, O, and P, we find that the excess of tenacity of the 1⅝″ bar over that of the 2″ is 4,163 pounds, 2,449 pounds, 5,721 pounds, 4,535 pounds, 3,207 pounds, 2,657 pounds, 4,596 pounds, 4,152 pounds, and 4,800 pounds, giving an average for the nine lots of 4,030 pounds, which is probably lower than it would be if the record of the irons, which were very thoroughly worked on all sizes, were omitted, as they might be, they all proving too soft and too expensive to be fairly considered as chain-irons. Assuming, however, this difference, which is probably a minimum as regards "chain-iron," the strength per square inch of a 1⅝″ bar would be 54,000 pounds, if that of the 2″ was 50,000 pounds, and the entire strength of the 1⅝″ would be 112,000 pounds, which is 71 per cent. of that of the 2″, viz, 157,000 pounds. (The 1½″ bar of iron E is substituted for the 1⅝″ for the reason that in this case the pile for the 1½″ was of the same area as that for the 2″.)

If the two bars, 2″ and 1⅝″, were equally valuable in every respect for cable, and both in link form developed the same percentage of the bar's strength, say 163 per cent., the strength of the 1⅝″ cable would be 182,600 pounds, which is 71 per cent. of that of the 2″, viz, 256,000 pounds, while its weight, 23,996 pounds, would be but 66.4 per cent. of that of the 2″, viz, 36,125 pounds. If it be considered that the loss in actual power to resist steady tension is not counterbalanced by the gain in reduced weight, the comparative powers to resist sudden strains should be considered. It is more than probable that the greater work given to the 1⅝″ will have so increased its ductility that its power to resist sudden strains will prove greater than that of the 2″ cable.

These views are borne out by many of our experiments, from which we will select the bars of iron N for comparison. This iron was sent to us by a prominent manufacturer in answer to an order for "samples of best cable-iron."

The 2″ bar had tenacity 51,748 pounds, and when broken by tension had very slight reduction of area and elongation; broken by impact, it proved very brittle, and while in no ways nicked or injured, would break like a pipe-stem by moderate blows.

Tested as cable, the links developed but 141 per cent. of the bar's strength, viz, 232,000 pounds.

The 1⅝″ bar, with tenacity 56,344 pounds, when tested by tension, reduced in area to 60 per cent. of the original and elongated 23 per cent.

Tested by impact it proved fairly tough, deflecting to over 60° before breaking, and when circled with a score resisted to a greater extent than did the 2″ in its normal condition.

Tested as cable, the links developed 164 per cent. of the bar's strength, breaking at 195,500 pounds, or at 84 per cent. of the strength of the 2″.

In this case there can be no doubt but that the smaller and lighter cable would have proved the most reliable.

Irregularity in strength is a great fault in cable-iron; this is more apt to occur in the large than in the small bars, one reason for which is that irregularity in heating the piles produces irregularity in strength, and to this the large bars are more greatly exposed than the small ones. The pile and resultant bar of 2″ weighs 400 or 500 pounds, and while passing through the rolls is, of course, much more difficult to handle than a lighter pile or bar; there are greater liabilities of "bucking" and "bending," and while the workmen are mauling the bar to straighten it, the next bar to be rolled is being delayed in the furnace, and the effects of variations in the heat are not provided against by regulating the latter. It seems but natural that if the pile for a small bar is heated enough for rolling in one hour, that portions of the large pile are in the same time equally ready, and that by longer delay in the furnace they become overheated.

The effect of overheating is to lower both the elastic limit and the strength.

Irregularity in the workmanship by which the links are manufactured produces irregular strength in the cable. To this the larger bars are exposed to a greater extent than the smaller ones; the *weld* is less apt to be perfect. A small bar is, when at the right heat, welded by a few quick blows, and the time of the operation is not great enough to allow the iron to become too cool. With a large bar it is different. It requires more and harder blows, and more time; and if at the right heat when the operation is begun, it may be too cool before it is ended, or in order that it shall not be, it may be heated a little too much on the start; the surface of the weld is greater, and is more exposed to the danger of interposition of ashes, dust, or scoria, either of which will prevent a perfect weld.

Finally, if the cable be finished without any accidental defect, the *proof* of the 2″ so far exceeds that of the 1⅝″, in proportion to its strength, that it is possible that the strength it may have had will be lowered by it.

For the reasons assigned we are of the opinion that the margin of safety secured by the use of a cable of 1⅝″ iron, weighing 12 tons, is equally as great as by the use of the 2″, weighing 18 tons.

SUBSTITUTION OF OPEN LINKS FOR STUDDED ONES PROPOSED AND DISCUSSED.

There exists a strong prejudice against the use of cables made from links without studs. This prejudice is based upon the opinion which is very generally entertained, that, first, the open link is not so strong as the studded one; second, that owing to the want of the support given to the sides by the stud when used, the open link will collapse at a much lower strain than the studded one will, and that this collapse will be so great that the links will nip each other and become rigid; and, third, that the liability of the relative position of the links becoming misplaced is greater with the open than with the studded links, from which cause jams may occur in the hawse-pipe when the cable is running out, or after having remained some time with a slack cable, a sudden squall tautening it might produce the same effect.

The first of these objections, viz, that the open link is weaker than the studded ones, our experiments show to be without foundation. The contrary is the case under most circumstances.

We are led by the results of our tests to doubt that the second objection exists to the extent generally supposed. We find that in all cases the open links *begin* to change form at a lower stress than the studded ones, but the sides having straightened somewhat, the stress is soon resisted by the tenacity of the material itself, and unless the iron is very soft and ductile (much more so than is usually the case with chain-iron), the closure does not continue to be rapid, and at an extreme stress, sufficient to rupture the studded link, if there be one in the section under test, the closure has not been so great as to unfit the open links for service.

With irons F and O, both extremely ductile, some of the open links were too much closed for service, but others were not, after having resisted the stress which broke the studded links. Such iron, however, will not often be made up into cables, and we have to a certain extent a resource by which this early closure of the sides may be delayed with all irons.

A cable made of bolts of ⅛″ greater diameter, without studs, will possess fully 20 per cent. more strength than the smaller studded cable, and will weigh but a trifle more. For instance, the weights and qualities may be compared by giving the data as to the two sizes, 1½″ and 1⅝″. Their weights would be as follows:

For 150 fathoms, or 10 sections, 1½″ studded cable:

	Pounds.
Number of links, 2,025; weight	19,643
Number of swivels, 4; weight	140
Number of shackles, 10; weight	195
Number of club-links, 1; weight	165
Total	20,143

For 150 fathoms, or ten sections, 1⅝″ unstudded-link cable:

	Pounds.
Number of links, 1,875; weight	21,356
Number of swivels, 4; weight	192
Number of shackles, 10; weight	240
Number of club-links, 1; weight	220
Total	22,008

Thus the difference in weight would be but 1,865 pounds.

The probable strength of the 1½″ studded would be at the greatest 157,000 pounds; that of the 1⅝″, if studded, 182,000 pounds, and if unstudded, considerably more, the minimum difference of 25,000 pounds being nearly 16 per cent. of the entire strength of the 1½″ cable. And as the action of the stud tends to pry open such welds as may not be perfect, the chances for regularity in strength are much increased by its omission. And it is more than probable that the extreme stress which the 1½″ would break at would not close the links of 1⅝″ to such extent as to render them unserviceable.

The third objection to the use of unstudded-link cables is that it is presumed that they are more liable to become fouled and kinked than the studded-link cable, while being stowed in the chain-locker, or when slack and the vessel changes her position without tautening the cable.

There are reasons based upon facts which actually exist, connected with the process of manufacture, which justify us in the assumption that the danger from this cause is not so great with unstudded-link as with studded-link cables.

Before giving these reasons, it will be admitted that with perfectly made studded links this greater liability of kinking may not exist, but links are not always perfect and of the dimensions given in the table (page 172). With such links, there is in each a space between the edge of the stud and the crown of the link of from ⅜″ on a 1″, to ⅝″ on a 2″, the link being made from a bolt of exactly twelve diameters in length, and the stud perfectly trimmed after casting, and adjusted to the exact center.

It often happens, either through fault in cutting or through "wasting in the fire," that the bolt is reduced to less than its proper length. Sometimes it happens that in bending the links one leg is left a little longer than the other. When the bolt is shortened by "wasting," its diameter at the end is also reduced, and the welder hits it a few times against the anvil, which, while driving back or upsetting the end, generally increases its diameter, and a *long* lap becomes necessary. If the link is unevenly bent, the same upsetting takes place by blows upon the long end. Thus, when made from a shortened bolt, there is a great probability of a large weld and of further shortening of the finished link by a long lap. Assuming a link to be thus finished and reduced, from any or all of the causes, in length, there arises from this shortness a probability that the stud will not be exactly centered. While being welded, the link is grasped by tht tongs at the butt; the thickness of the tongs, together with that of the finished link, which passes through the butt end of the one being welded, prevent the stud from being placed too near to the butt, and make it very probable that it will be fixed a little off center toward the weld end.

The link being thus shortened, and the stud too near the weld end, still another reason may arise which may cause a still further reduction of the space between stud and crown; the edge of the stud may not be smooth. After casting, a "gate" is frequently left on the edge of the stud through want of care in cutting and trimming with a cold-chisel.

Through the operation of any, or perhaps all, of these causes the space may be so much reduced that a jam is rendered highly probable at any time when through any cause the normal position of the links is altered.

In the cut, Fig. 1 represents a 1″ studded link, half-size, two others passing through it.

In Fig. 2 the same link is shown as it would appear if shortened $\frac{3}{16}$″; the solid lines of the stud show it as placed in the exact center; the dotted lines show a very possible inacuracy in its adjustment, by which the space is diminished to $\frac{1}{8}$″. If it be still further reduced by imperfection of the stud, the chances for kinking are great.

Of course, links need not be made thus imperfect, but they *frequently are* to a greater or lesser extent. Chain-welders generally do "task-work," and will take the chances of an imperfect link escaping detection by inspection, rather than expend considerable unremunerated time in cutting out and replacing defective links. Were the links without studs, the reduction in length would in no way decrease their value. The inside diameter of the links, $3\frac{3}{4}$″ × $1\frac{5}{8}$″ on a 1″ link, and $6\frac{7}{8}$″ × $3\frac{1}{4}$″ on a 2″, is not great enough to permit the links to become completely shifted in their relative positions. And as when the two links within a third are as close to one end of the third as they can get, there is still a considerable portion of the one nearest to the center of the third which through its diameter reaches past the central transverse axis, which portion will be greater if the third or center link is shortened, the effect of tension would be to cause the three to at once assume their proper position.

Although we have made no experiments to determine, we believe that the shorter link would possess more strength than the other.

A vessel which would be provided with 150 fathoms of studded $1\frac{1}{2}$″ cable would probably be more safely fitted out with 105 fathoms of unstudded $1\frac{5}{8}$″, and the weight could be thus safely reduced from 20,143 pounds to 18,000 pounds.

RECORD OF TESTS BY TENSION UPON SECTIONS OF CABLE-LINKS AND UPON BARS OF THE IRON FROM WHICH LINKS WERE MADE.

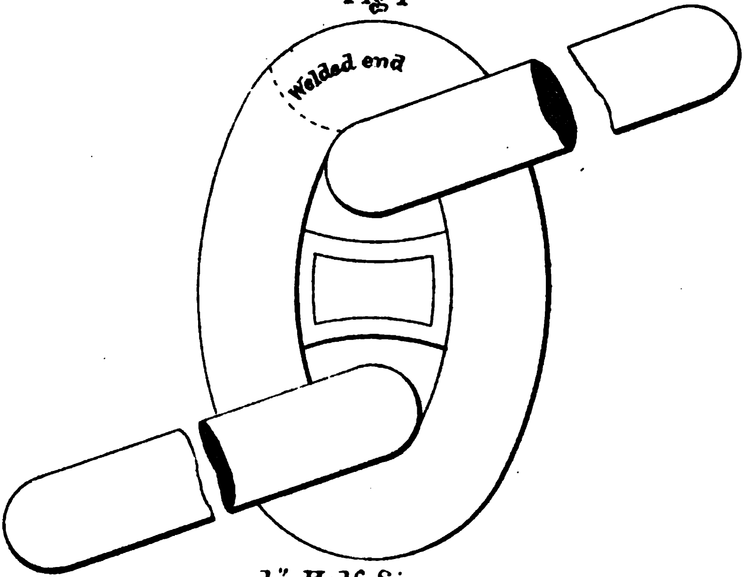
It was considered that if there existed, as seemed probable, a relationship between the strength and other properties of the round bar, and those of the links made from it, that it would be a valuable result to determine such relationship, and to find to how great an extent it could be depended upon, and within what margins it existed.

If such a relationship could be found which, within narrow and well-defined limits, indicated that the strength found in the bar furnished valuable evidence as to the probable strength of the links made from it, the information would prove of great value, inasmuch as the simple and inexpensive test of tension upon a portion of a bar would provide data by which the probable strength of a cable made from it could be judged.

The following tables have been prepared for the purpose of developing this relationship and finding its margins.

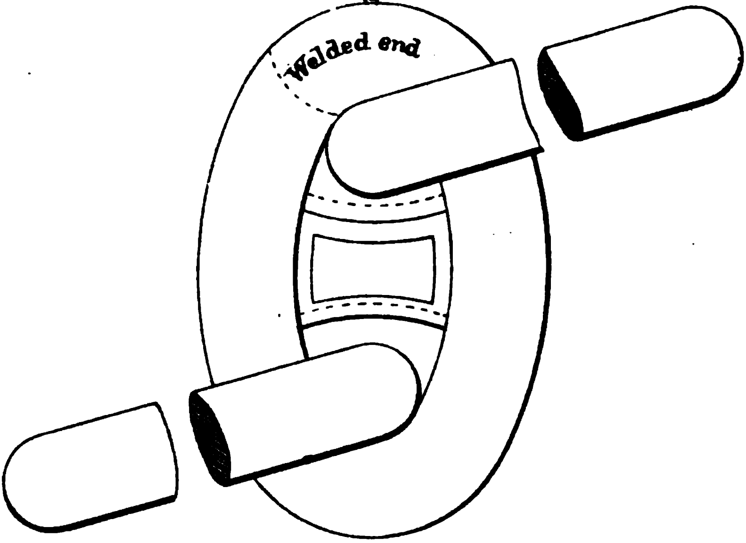
We find that with iron of moderate tenacity and with good welding properties the percentage of the bar's strength, which is carried with great uniformity into the link, is from 160 to 175 per cent.; that with irons of unsuitable qualities this percentage is frequently low and frequently high, it being very irregular, and averages of less than 155 per cent. made up of very irregular factors are common, and that with the

Fig 1



1" Half Size
Length of Link $5\frac{11}{16}$"
Width . . $3\frac{2}{16}$"

Fig 2



1" Links short $\frac{5}{16}$"
Solid lines show stud
in centre. Dotted lines
possible misplacement

best chain-iron, although there may be links which develop over 175 per cent., such cases are rare.

These tables also contain a column in which in each case the stress which broke the cable is reduced to the square inch, in order to ascertain the effect, upon the strength of the transverse section of the end, of the change of form from a straight bar to a sharp arch.

These tables furnish many of the data which have been utilized by us in the calculation of the proof-table contained in this report.

Strength of chain cables tested as short sections and single links.

[With approximate elastic limit of links, location of rupture, and percentage of strength of original bars developed by the links.]

IRON A.

SHORT SECTIONS FROM BARS NOS. 112 TO 162.

Test number.	Diameter of bar.	Number of links in test.	Stress in pounds.			Location of fracture.	Ratio between first stretch and fracture.	Stretch of unbroken links.	Strength of bars.	Strength of links in per cent. of bars.
			First stretch was observed.	Fracture took place.	Borne by end per square inch sectional area.					
	"							"		
1	1¼	2	26,880	72,672	88,938	Qr. B	34.0	1.00	....	164.6
2		2	29,760	71,712	87,764	Qr. B	41.5	1.15	....	162.4
3		5	27,840	69,600	88,617	Qr. W	40.0	1.30	....	156.8
Av.	......	....	**28,160**	**71,328**	**88,441**	....	**39.5**	**1.15**	**44,126**	**161.3**
4	1⅛	2	34,560	88,800	88,534	Qr. W	38.9	1.10	....	164.4
5		3	41,280	89,280	89,012	Qr. B	46.2	1.20	....	165.4
Av.	......	....	**37,920**	**89,040**	**88,773**	....	**42.5**	**1.15**	**53,997**	**164.9**
6	1¼	2	45,120	110,880	90,336	Qr. W	40.7	1.40	....	167.8
7		3	48,960	118,480	95,012	Qr. W	41.3	1.00	....	179.2
Av.	......	...	**47,040**	**114,680**	**92,689**	....	**41.0**	**1.20**	**66,112**	**173.5**
8	1⅜	2	57,600	132,480	89,877	Qr. W	43.5	1.30	....	168.0
9		3	58,560	136,320	92,483	Qr. W	42.9	1.70	....	172.6
Av.	......	....	**58,080**	**134,400**	**91,180**	....	**43.2**	**1.50**	**78,944**	**170.3**
10	1½	2	65,300	147,840	83,667	Side	42.2	1.60	....	161.2
11		3	72,000	159,360	90,186	Qr. W	52.2	1.80	....	173.8
Av.	......	....	**68,650**	**153,600**	**86,926**	....	**44.7**	**1.65**	**91,680**	**167.5**
12	1⅝	2	71,040	169,000	82,000	Side	42.0	1.20	....	150.8
13		3	81,600	179,520	87,103	Thro. W ...	45.5	1.50	....	160.4
Av.	......	....	**76,320**	**174,260**	**84,551**	....	**43.7**	**1.35**	**111,984**	**155.6**
14	1¾	2	85,440	216,000	90,832	Qr. B	39.6	1.70	....	174.0
15		3	87,360	213,120	87,595	Qr. W	41.0	2.00	....	172.0
Av.	......	....	**86,400**	**214,560**	**89,213**	....	**40.3**	**1.85**	**123,840**	**173.0**
16	1⅞	2	96,000	252,960	91,125	Side	38.0	2.00	**141,120**	**176.0**
17	2	2	101,000	270,240	86,009	Qr. B	....	....	....	171.4
18		2	100,800	268,224	85,367	Qr. W	....	....	....	170.2
Av.	......	....	**100,900**	**269,232**	**85,688**	....	....	....	**162,240**	**170.8**
19	2	2	....	283,200	90,134	Qr. B	....	1.70	....	178.4
20		2	....	260,382	82,871	Qr. W	....	1.54	....	165.2
21		2	....	257,260	81,877	Qr. B	....	1.61	....	162.0
22		2	....	269,000	85,614	Qr. B	....	1.60	....	170.6
23		2	....	248,000	78,930	Qr. B	....	1.47	....	157.4
24		2	....	244,000	77,657	Thro. B....	....	1.36	....	....
25		2	....	279,936	89,093	Thro. B....	....	1.66	....	177.6
26		2	....	270,240	86,009	Qr. B	....	....	....	171.4
Av.	......	....	....	**264,002**	**84,023**	....	....	**1.56**	**157,588**	**168.9**

Strength of chain cables, &c.—Continued.

IRON A—Continued.

SINGLE LINKS FROM SAME BARS.

Test number.	Diameter of bar.	Number of links in test.	Stress in pounds. First stretch was observed.	Stress in pounds. Fracture took place.	Stress in pounds. Borne by end per square inch sectional area.	Location of fracture.	Ratio between first stretch and fracture.	Stretch of unbroken links.	Strength of bars.	Strength of links in per cent. of bars.
	″							″		
27	1	....	....	75, 936	96, 684	Side	....	....	....	172. 0
23		....	29, 840	76, 320	97, 173	Qr. B	39. 2	....	....	173. 0
Av.	......	....	29,840	76,128	96,928	....	39.2	....	44,126	172.5
29	1⅛	....	44, 160	94, 080	94, 648	Qr. B	46. 8	....	....	174. 2
30		....	....	96, 600	97, 183	Qr. B	....	....	....	178. 8
Av.	......	....	44,160	95,340	95,915	....	46.3	....	53,997	176.5
31	1¼	....	46, 770	111, 360	90, 757	Qr. W	42. 0	....	66,112	168.4
32	1⅜	....	55, 680	134, 880	90, 828	Qr. W	41. 3	....	78,944	170.8
33	1½	....	65, 740	158, 400	89, 643	Qr. W	41. 5	....	91,680	172.8
34	1⅝	....	72, 960	184, 800	89, 108	Qr. W	39. 4	....	111,984	165.0
35	1¾	....	86, 400	215, 520	89, 613	Qr. B	40. 0	....	123,840	174.0
36	1⅞	....	101, 760	252, 480	91, 445	Side	40. 3	....	141,120	179.0
37	2	....	....	293, 760	93, 494	Thro. B....	....	....	162,240	181.0

IRON B.

SINGLE LINKS FROM SAMPLE BARS NOS. 168 TO 174.

Test number.	Diameter of bar.	Number of links in test.	Stress in pounds. First stretch was observed.	Stress in pounds. Fracture took place.	Stress in pounds. Borne by end per square inch sectional area.	Location of fracture.	Ratio between first stretch and fracture.	Stretch of unbroken links.	Strength of bars.	Strength of links in per cent. of bars.
38	1 7/16	1	75, 260	149, 760	92, 274	Qr. W	50. 3	....	....	....
39		1	78, 400	153, 020	94, 282	Qr. W	51. 2	....	....	....
40		1	67, 200	162, 050	99, 846	Qr. W	41. 5	....	....	....
41		1	83, 900	150, 530	92, 748	Qr. W	55. 7	....	....	....
42		1	84, 100	136, 700	84, 226	Qr. W	61. 5	....	....	....
Av.	......	....	77,762	150,412	92,675	....	52.0	....	89,090	168.8
43	1 11/16	....	....	218, 120	95, 813	Qr. W	....	....	....	....
44		1	101, 760	208, 140	90, 850	Qr. W	50. 0	....	....	....
45		1	115, 000	221, 950	99, 262	Qr. W	56. 0	....	....	....
Av.	......	....	108,350	212,737	95,142	....	53.0	....	121,150	175.6
46	1 13/16	1	103, 100	234, 050	90, 717	Qr. W	....	....	....	....
47		1	121, 340	228, 860	88, 705	Qr. B	....	....	....	....
48		1	122, 690	240, 770	93, 321	Qr. W	....	....	....	....
49		1	118, 460	233, 280	90, 418	Qr. W	....	....	....	....
50		1	110, 400	219, 260	84, 984	Qr. W	....	....	....	....
51		1	117, 310	225, 220	87, 294	Qr. W	....	....	....	....
52		1	113, 280	239, 420	92, 728	Qr. W	....	....	....	....
Av.	......	....	115,226	231,551	89,748	....	50.4	....	142,660	162.3

SHORT SECTIONS FROM IRON DELIVERED, BARS NOS. 816 TO 825.

Test number.	Diameter of bar.	Number of links in test.	Stress in pounds. First stretch was observed.	Stress in pounds. Fracture took place.	Stress in pounds. Borne by end per square inch sectional area.	Location of fracture.	Ratio between first stretch and fracture.	Stretch of unbroken links.	Strength of bars.	Strength of links in per cent. of bars.
53	1 7/16	2	62, 000	154, 000	94, 886	Qr. B	40. 2	....	....	181. 4
54		2	62, 000	149, 000	91, 805	Qr. B	41. 6	1. 06	....	175. 6
55		2	59, 000	150, 000	92, 431	Thro. W...	39. 3	1. 50	....	176. 6
56		2	56, 000	152, 000	93, 683	Thro. W ..	36. 8	1. 50	....	179. 0
57		2	57, 700	152, 600	94, 021	Thro. W...	37. 8	1. 50	....	179. 2
58		2	59, 000	151, 700	93, 468	Thro. W...	38. 8	1. 44	....	178. 6
59		2	57, 500	139, 600	86, 013	Thro. W...	41. 2	1. 00	....	164. 4
60		2	57, 500	140, 000	86, 260	Thro. W...	41. 1	1. 20	....	164. 8
61		2	75, 840	154, 750	95, 348	Qr. W	49. 0	1. 10	....	182. 4

Strength of chain cables, &c.—Continued.

IRON B—Continued.

SHORT SECTIONS FROM IRON DELIVERED, BARS NOS. 316 TO 325—Continued.

Test number.	Diameter of bar.	Number of links in test.	Stress in pounds. First stretch was observed.	Stress in pounds. Fracture took place.	Stress in pounds. Borne by end per square inch sectional area.	Location of fracture.	Ratio between first stretch and fracture.	Stretch of unbroken links.	Strength of bars.	Strength of links in per cent. of bars.
	″							″		
62	1$\frac{7}{16}$	2	62, 590	155, 040	95, 526	Qr. W	40. 4	....	....	182. 6
63		2	65, 280	144, 480	89, 020	Qr. W	45. 1	1. 10	....	170. 2
64		2	60, 000	150, 700	92, 852	Qr. W	39. 8	1. 60	....	177. 0
65		5	67, 970	153, 400	94, 516	Thro. W ...	44. 3	....	....	180. 8
Av.	......	....	61,721	149,790	92,293	....	41.1	1.32	84,862	176.4
66	1$\frac{11}{16}$	2	88, 700	194, 880	87, 155	Qr. W	....	....	....	164. 8
67		2	89, 870	199, 680	89, 302	Qr. W	....	....	....	168. 8
68		2	87, 740	196, 990	88, 100	Qr. W	....	....	....	166. 6
69		5	85, 440	201, 020	89, 990	Qr. W	....	....	....	....
Av.	......	....	87,937	198,144	86,637	....	44.4	1.28	118,278	136.7
70	1$\frac{13}{16}$	2	89, 090	231, 940	89, 899	Qr. W	38. 4	....	....	169. 2
71		2	....	212, 700	89, 441	Qr. W	43. 0	....	....	155. 2
72		2	99, 260	235, 070	89, 368	Qr. W	44. 5	....	....	168. 2
73		5	94, 080	211, 390	81, 934	Qr. W	....	....	....	154. 2
Av.	......	....	94,143	221,650	85,910	....	41.5	....	137,028	161.7

UNSTUDDED SECTIONS FROM BARS NOS. 316 TO 319.

Test number.	Diameter of bar.	Number of links in test.	Stress in pounds. First stretch was observed.	Stress in pounds. Fracture took place.	Stress in pounds. Borne by end per square inch sectional area.	Location of fracture.	Ratio between first stretch and fracture.	Stretch of unbroken links.	Strength of bars.	Strength of links in per cent. of bars.
74	1$\frac{7}{16}$	2	49, 200	158, 400	97, 597	Thro. W ...	31. 0	1. 25	....	186. 6
75		2	55, 700	156, 500	96, 426	Qr. W	35. 6	1. 50	....	184. 4
76		2	46, 000	164, 650	101, 447	Qr. B	27. 9	1. 75	....	194. 0
77		2	49, 000	157, 000	96, 734	Qr. W	31. 2	1. 60	....	185. 0
78		2	53, 000	159, 500	98, 275	Qr. W	33. 2	1. 44	....	186. 8
79		2	50, 000	163, 200	100, 554	Qr. W	36. 0	1. 75	....	184. 4
80		2	50, 000	160, 000	98, 582	Qr. W	31. 2	1. 25	....	188. 4
81		2	57, 000	151, 700	93, 468	Qr. W	37. 5	1. 44	....	178. 8
82		2	55, 000	147, 300	90, 758	Qr. W	37. 3	1. 32	....	173. 6
83		2	56, 500	152, 000	93, 638	Qr. W	37. 1	1. 12	....	179. 0
Av.	......	....	52,140	157,025	96,752	....	33.3	1.44	84,862	184.0

The unbroken links of the above sections were again pulled, with the result as given below:

Test number.	Number of links in test.	Stress in pounds. Fracture took place.	Stress in pounds. Borne by end per square inch sectional area.	Location of fracture.	Test number.	Number of links in test.	Stress in pounds. Fracture took place.	Stress in pounds. Borne by end per square inch sectional area.	Location of fracture.
84	1	142, 000	87, 492	Thro. W.	90	1	168, 500	103, 820	Thro. B.
85	1	....	....	End lk.	91	1	169, 100	98, 028	Thro. W.
86	1	167, 000	102, 895	Thro. W.	92	1	....	....	End lk.
87	1	157, 000	96, 734	Thro. W.	93	1	164, 200	101, 170	Thro. B.
88	1	170, 000	104, 744	Thro. B.					
89	1	165, 600	102, 033	Thro. B.	Av.	....	161,662	99,614	

Strength of chain cables, &c.—Continued.

IRON C.

SINGLE LINKS FROM BARS NOS. 175 TO 180, AND NOS. 353 TO 372.

Test number.	Diameter of bar.	Number of links in test.	Stress in pounds.			Location of fracture.	Ratio between first stretch and fracture.	Strength of bars.	Strength of links in per cent. of bars.
			First stretch was observed.	Fracture took place.	Borne by end per square inch sectional area.				
	"								
94	1⅛	1	48, 600	101, 800	102, 414	Thro. W	47. 6		
Av.								57,125	178.2
95	1¼	1	63, 400	122, 100	95, 436	Qr. W	51. 9		171. 8
			59, 500	124, 800	101, 711	Side	47. 7		175. 6
Av.			61,450	123,450	98,573		49.8	71,040	173.6
96	1⅜	1	84, 500	134, 800	90, 774	Qr. W	62. 7		165. 2
97		1	67, 200	132, 000	88, 888	Qr. W	50. 9		161. 8
Av.			75,850	133,400	89,831		56.8	81,600	163.4
98*	1 7/16	1		149, 600	92, 175	Qr. W		84, 000	178. 0
99*	1½	1		178, 200	100, 859	Qr. W			191. 4
100		1	67, 200	160, 560	94, 261	Side	40. 3		170. 0
101		1	66, 720	163, 680	92, 631	Weld	40. 8		167. 1
102		1	72, 960	164, 640	93, 175	Qr. B	44. 3		168. 1
103		1	68, 160	165. 600	93, 718	Side	41. 2		169. 1
104		1	70, 800	168, 900	95, 619	Side	41. 9		171. 5
105		1	73, 000	167, 000	94, 510	Side	43. 7		170. 5
106		1	76, 800	174, 700	98, 868	Qr. W	43. 9		178. 4
107		1	78, 700	176, 300	99, 773	Side	44. 6		180. 0
108		1	82, 600	171, 800	97, 277	Qr. W	48. 0		175. 4
109		1	77, 700	173, 400	98, 132	Qr. W	44. 8		177. 0
Av.			73,464	169,264	95,796		43.4	97,921	172.7
110*	1⅝	1		192, 900	93, 007	Qr. W			189. 6
111		1	81, 600	178, 600	86, 113	Qr. W	45. 7		154. 2
112		1	82, 600	190, 100	91, 658	Qr. W	43. 5		164. 0
113		1	88, 800	199, 300	96, 094	Qr. B.	44. 3		173. 0
114		5	81, 600	186, 800	90, 067	Qr. W	43. 7		161. 2
115		1	81, 600	203, 500	98, 119	Qr. W	40. 0		175. 6
116		1	78, 700	197, 800	95, 371	Qr. W	39. 8		170. 8
Av.			82,400	192,685	92,904		42.8	115,749	166.4
117*	1 11/16			197, 800	88, 461	Qr. W		111, 400	177. 6
		1							
118*	1¾	1		241, 000	100, 207	Qr. W			199. 0
119		1	90, 800	200, 600	83, 904	Qr. B.	45. 2		153. 2
120		1	87, 400	237, 100	98, 585	Qr. W	36. 8		181. 2
121		1	105, 600	228, 500	95, 010	Qr. W	46. 2		174. 6
122		1	96, 000	226, 500	94, 178	Qr. W	42. 4		173. 0
123		1	98, 900	256, 300	106, 570	Qr. W	38. 5		195. 8
124		1	97, 900	232, 300	96, 590	Qr. W	42. 1		177. 4
Av.				230,217				130,835	175.8
125*	1 13/16	1		227, 300		Qr. W		131, 500	172. 8
SHORT SECTIONS FROM THE SAME BARS.									
126	1½	2	63, 400	162, 800	92, 133	B	38. 9		167. 0
127		2	66, 200	159, 400	90, 209	B	41. 5		163. 0
128		3	69, 100	160, 300	90, 719	Qr. W	43. 0		164. 4
129		5	63, 400	147, 000	83, 190	Qr. W	63. 1		150. 8
130		7	73, 000	163, 700	92, 643	B	44. 6		168. 0
131		10	72, 000	157, 000	88, 850	Qr. B	45. 9		161. 2
132		10	52, 800	155, 100	87, 777	B	34. 0		159. 0
Av.			65,700	157,900	89,360		44.4	97,921	161.9
133	1⅝	2	78, 700	185, 300	89, 344	Qr. B	42. 5		160. 0
134		2	76, 800	184, 900	89, 151	Qr. B	41. 5		158.0
135		3	98, 900	174, 700	84, 233	Qr. W	56. 6		150. 0
136		5	89, 300	1[illegible], 900	93, 973	Qr. W	48. 8		168. 4
137		7	85, 400	177, 100	85, 390	Qr. W	48. 2		153. 0
138		10	85, 400	188, 200	90, 742	Qr. B	45. 4		162. 4
139		10	61, 100	158, 400	76, 374	Qr. B	38. 6		136. 8
Av.			82,229	180,500	87,030		45.5	115,749	155.5

Links marked * were from original sample bars, the remainder chain-iron delivered of 1½", 1⅝", 1¾", and purchased bars.

Strength of chain cables, &c.—Continued.

IRON C—Continued.

SHORT SECTIONS FROM THE SAME BARS—Continued.

Test number.	Diameter of bar.	Number of links in test.	Stress in pounds. First stretch was observed.	Stress in pounds. Fracture took place.	Stress in pounds. Borne by end per square inch sectional area.	Location of fracture.	Ratio between first stretch and fracture.	Stretch of unbroken links.	Strength of bars.	Strength of links in per cent. of bars.
	"							"		
140	1¾	2	88,800	225,600	93,804	Qr. B	39.1	......	......	172.4
141		2	81,600	231,300	96,174	Qr. W	35.2	......	......	176.7
142		3	98,900	207,400	86,231	W	47.7	......	......	158.5
143		3	86,400	195,800	81,414	W	44.1	......	......	149.6
144		3	92,200	170,900	71,060	Qr. W	53.9	......	......	130.6
145		5	97,900	196,800	81,829	W	49.7	......	......	150.4
146		5	101,800	193,000	80,249	Qr. W	52.7	......	......	147.5
147		5	95,000	175,700	72,056	W	54.0	......	......	134.3
148		7	87,400	212,200	88,232	Qr. B	41.1	......	......	162.2
149		7	103,700	192,000	79,800	Qr. W	54.0	......	......	146.7
150		7	85,400	203,500	84,615	Qr. W	42.0	......	......	155.5
151		10	97,000	202,600	84,240	Qr. W	47.8	......	......	154.8
152		10	57,600	191,000	79,418	Qr. W	30.0	......	......	150.0
Av.	......	....	**90,554**	**199,830**	**83,009**	......	**45.5**	......	**130,835**	**153.0**

IRON D (FIRST LOT).

SINGLE LINKS FROM BARS NOS. 410 TO 417.

Test number.	Diameter of bar.	Number of links in test.	Stress in pounds. First stretch was observed.	Stress in pounds. Fracture took place.	Stress in pounds. Borne by end per square inch sectional area.	Location of fracture.	Ratio between first stretch and fracture.	Stretch of unbroken links.	Strength of bars.	Strength of links in per cent. of bars.
153	1⅛	1	37,900	97,400	97,988	Butt	38.9	......	......	178.6
154		1	36,500	95,000	95,573	Qr. W	38.4	......	......	174.0
Av.	......	....	**37,200**	**96,200**	**96,780**	......	**38.6**	......	**54,360**	**176.3**
155	1¼	1	53,800	124,800	101,711	Qr. W	43.1	......	68,160	182.0
156		1	......	122,800	100,081	Qr. B	......	......	......	180.0
Av.	......	....	**53,800**	**123,800**	**100,896**	......	**43.1**	......	68,160	**181.0**
157	1⅜	1	57,600	144,800	97,508	Qr. W	39.8	......	81,600	177.4
158		1	......	142,000	95,622	Side	......	......	......	174.0
Av.	......	....	**57,600**	**143,400**	**96,565**	......	**39.8**	......	81,600	**175.7**
159	1½	1	70,600	178,500	101,018	Side	39.6	......	......	193.6
160		1	73,000	178,100	100,792	Qr. W	41.0	......	......	193.2
Av.	......	....	**71,800**	**178,300**	**100,905**	......	**40.3**	......	**92,160**	**193.4**
161	1⅝	1	85,000	199,700	96,287	Qr. W	42.5	......	111,360	179.2
162	1¾	1	94,100	231,400	96,216	Qr. W	41.0	......	126,720	182.6
163	1⅞	1	94,600	238,100	86,236	Qr. W	40.0	......	142,080	167.6
164	2	1	134,400	276,500	88,000	Qr. W	48.5	......	160,700	172.0

SHORT SECTIONS, SECOND LOT, 1877, FROM BARS NOS. 418 TO 428.

Test number.	Diameter of bar.	Number of links in test.	Stress in pounds. First stretch was observed.	Stress in pounds. Fracture took place.	Stress in pounds. Borne by end per square inch sectional area.	Location of fracture.	Ratio between first stretch and fracture.	Stretch of unbroken links.	Strength of bars.	Strength of links in per cent. of bars.
165	1	3	36,200	79,200	100,843	Qr. W	45.7	1.25	48,000	165.0
166	1⅛	3	45,000	87,500	88,814	Qr. W	51.4	1.55	58,700	149.0
167	1¼	3	55,200	113,000	90,617	Qr. W	48.8	1.60	72,300	156.3
168	1⅜	3	71,500	137,200	91,711	Qr. W	52.1	2.25	86,800	158.0
169	1½	3	80,100	173,000	97,906	Qr. W	46.3	2.50	101,200	170.8
170	1⅝	3	90,000	182,000	88,306	Qr. W	49.5	3.00	110,500	164.8
171	1¾	3	99,000	204,000	84,823	Qr. W	48.5	3.10	128,600	158.6
172	1⅞	3	112,300	215,000	76,468	Thro. W	52.2	3.75	149,000	144.2
173	2	3	116,000	240,000	77,947	Not broken	......	......	{ 142,100 149,800	....
Av.	......	....	......	......	......	......	......	......	**145,950**	**164.4**

Strength of chain cables, &c.—Continued.

IRON E.

SINGLE LINKS FROM BARS NOS. 181 TO 204, 476 TO 498.

Test number.	Diameter of bar.	Number of links in test.	Stress in pounds.			Location of fracture.	Ratio between first stretch and fracture.	Stretch of unbroken links.	Strength of bars.	Strength of links in per cent. of bars.
			First stretch was observed.	Fracture took place.	Borne by end per square inch sectional area.					
	″							″		
174	1⅛	1	44, 200	87, 400	84, 120	Qr. W......	50. 6	....	....	158. 4
175		1	43, 800	90, 200	86, 814	Qr. W......	48. 6	....	....	163. 6
176		1	43, 000	85, 500	82, 290	Qr. W......	50. 3	....	....	155. 0
177		1	43, 800	87, 500	84, 215	Qr. W......	50. 0	....	....	....
Av.	......	....	**43,700**	**87,650**	**84,360**	....	**49.9**	....	**55,152**	**158.9**
178	1¼	1	44, 200	112, 500	90, 216	Qr. B	39. 3	....	....	167. 4
179		1	44, 600	119, 000	95, 429	Qr. B	35. 7	....	....	177. 0
180		1	45, 100	109, 400	87, 730	Qr. W......	41. 2	....	....	162. 8
181		1	44, 600	113, 700	91, 178	Qr. W......	39. 2	....	....	169. 2
Av.	......	....	**44,625**	**113,650**	**91,138**	....	**39.3**	....	**67,200**	**169.1**
182	.⅜	1	53, 800	132, 600	87, 409	Qr. W......	40. 6	....	....	167. 2
183		1	53, 800	137, 700	90, 771	Qr. W......	39. 0	....	....	173. 6
184		1	55, 700	130, 100	85, 761	Qr. W......	42. 8	....	....	164. 6
185		1	54, 700	139, 200	91, 760	Qr. W......	39. 3	....	....	175. 6
Av.	......	....	**54,500**	**134,900**	**88,925**	....	**40.4**	....	**79,296**	**170.2**
186	1 7/16	1	....	162, 432	100, 081	Qr. B	....	....	87, 552	185. 6
187	1½	1	....	179, 520	101, 584	Qr. W......	....	....	96, 384	186. 0
188		1	65, 800	162, 400	91, 907	Qr. W......	40. 2	....	....	165. 8
189		1	72, 000	158, 900	89, 926	Qr. W......	45. 3	....	....	162. 2
Av.	......	....	**68,650**	**160,650**	**90,916**	....	**42.7**	....	97, 920	**164.0**
190	1⅝	....	....	205, 056	98, 870	Qr. B	....	....	109, 248	187. 7
191	1⅝	1	73, 000	194, 300	93, 196	Qr. W......	37. 6	....	....	179. 2
192		1	71, 500	185, 300	88, 787	Qr. B	38. 6	....	....	171. 0
Av.	......	....	**72,250**	**189,800**	**90,991**	....	**38.1**	....	108, 384	**175.1**
193	1 11/16	1	....	213, 696	95, 570	Qr. B	....	....	116, 544	183. 2
194	1¾	1	....	218, 304	90, 770	Qr. B	....	....	119, 808	182. 2
195	1¾	1	91, 000	221, 500	92, 099	Qr. W......	41. 0	....	124, 128	178. 4
196	1 13/16	1	....	234, 816	91, 014	Qr. B	....	....	129, 792	180. 9
197	1⅞	1	92, 600	243, 600	86, 845	Qr. W......	38. 0	....	....	170. 0
198		1	95, 000	223, 600	78, 871	Qr. W......	42. 5	....	....	156. 4
Av.	......	....	**93,800**	**233,600**	**82,858**	....	**40.2**	....	**142,991**	**163.2**

IRON F (FIRST LOT).

SHORT SECTIONS OF CABLE LINKS, FROM BARS NOS. 499 TO 514.

199	1⅛	2	28, 500	86, 400	87, 698	Qr. W......	33. 0	. 60	**53,850**	**162.8**
200	1¼	2	50, 000	101, 700	82, 855	Qr. W......	49. 1	....	**64,990**	**156.4**
201	1⅜	2	51, 000	119, 000	79, 545	Qr. W......	42. 9	. 90	**77,285**	**154.0**
202	1½	2	60, 540	155, 500	88, 002	Thro. B	38. 9	1. 00	**91,875**	**169.2**
203	1⅝	2	71, 000	174, 700	84, 764	Thro. B....	40. 6	1. 00	**107,520**	**162.5**
204	1¾	2	76, 400	203, 500	84, 615	Qr. W......	37. 5	1. 90	**121,920**	**166.9**
205	1⅞	2	83, 500	230, 900	83, 177	Qr. W......	36. 1	2. 40	**140,925**	**163.8**
206	2	2	105, 000	268, 750	86, 414	Qr. W......	39. 1	....	**152,260**	**176.5**

Strength of chain cables, &c.—Continued.

IRON F (FIRST LOT)—Continued.

SINGLE LINKS FROM THE SAME BARS.

Test number.	Diameter of bar.	Number of links in test.	Stress in pounds. First stretch was observed.	Stress in pounds. Fracture took place.	Stress in pounds. Borne by end per square inch sectional area.	Location of fracture.	Ratio between first stretch and fracture.	Stretch of unbroken links.	Strength of bars.	Strength of links in per cent. of bars.
	″									
207	1⅛	....	44, 700	97, 900	99, 370	Qr. W......	....	....	....	....
208		....	43, 700	94, 100	95, 513	Qr. W......	....	....	....	....
Av.	......	....	**44,200**	**96,000**	**97,441**	....	**46**	....	**52,990**	**181.0**
209	1¼	....	50, 500	115, 200	93, 888	....	....	....	....	177. 2
210		....	49, 500	113, 300	92, 339	....	....	....	....	174. 4
Av.	......	....	**50,000**	**114,250**	**93,113**	....	**3.7**	....	**64,990**	**175.8**
211	1⅜	....	63, 600	136, 800	91, 443	Qr. W......	....	....	....	177. 1
212		....	65, 000	135, 400	90, 508	Qr. B.......	....	....	....	175. 8
Av.	......	....	**64,300**	**136,100**	**90,975**	....	**47.2**	....	**77,235**	**176.2**
213	1½	....	68, 640	152, 600	86, 360	Thro. B	44. 8	....	**91,875**	**166.0**
214	1⅝	....	76, 800	189, 100	91, 751	Qr. W......	40. 6	....	**107,520**	**175.8**
215	1¾	....	....	210, 200	87, 401	Qr. W......	....	....	**121,920**	**172.4**
216	1⅞	....	....	223, 200	80, 403	Qr. W......	....	....	**140,925**	**158.0**

IRON F (THIRD LOT).

SHORT SECTION OF CABLE-LINKS, FROM BARS NOS. 679 TO 704 AND 735 TO 752.

Test number.	Diameter of bar.	Number of links in test.	Stress in pounds. First stretch was observed.	Stress in pounds. Fracture took place.	Stress in pounds. Borne by end per square inch sectional area.	Location of fracture.	Ratio between first stretch and fracture.	Stretch of unbroken links.	Strength of bars.	Strength of links in per cent. of bars.
217	1	3	35, 600	67, 600	84, 372	Thro. W ...	52. 6	....	**41,600**	**162.4**
218	1⅛	3	47, 600	85, 000	84, 745	Thro. W ...	56. 0	....	**50,300**	**168.8**
219	1¼	3	55, 000	107, 600	87, 693	Thro. W ...	51. 1	....	**64,700**	**166.0**
220	1⅜	3	65, 600	128, 600	85, 962	Thro. B	51. 0	....	**78,300**	**164.2**
221	1½	3	70, 600	150, 500	85, 172	Qr. W......	47. 0	....	**89,800**	**167.6**
222	1⅝	3	90, 000	197, 600	83, 095	Qr. W	45. 5	....	**120,200**	**164.6**
223	1¾	3	90, 000	21[illegible], 600	78, 514	Thro. W ...	41. 7	....	**136,600**	**157.8**
224	1	3	100, 600	233, 600	73, 621	Thro. W ...	43. 0	....	**151,900**	**148.8**
225	¼	5	1, 500	3, 825	77, 290	Weld	39. 2	....	....	131. 0
226		5	1, 600	4, 000	80, 000	Thro. W ...	40. 0	....	....	137. 0
227		5	1, 500	3, 500	70, 720	Thro. W ...	42. 8	....	....	119. 9
Av.	......	....	**1,533**	**3,775**	**76,003**	....	**40.7**	....	2, 919	**129.3**
228	⅜	5	4, 000	8, 275	74, 950	Thro. W ...	48. 3	....	....	139. 1
229		5	3, 800	9, 000	81, 520	Thro. W ...	42. 2	....	....	151. 3
230		5	3, 900	8, 840	75, 550	Thro. W ...	46. 7	....	....	140. 0
231		5	3, 800	10, 050	90, 570	Qr. B	37. 8	....	....	169. 1
Av.	......	....	**3,875**	**8,916**	**80,647**	....	**43.7**	....	**5,949**	**149.9**
232	½	5	4, 200	17, 600	89, 660	Qr. W......	28. 8	....	....	170. 1
233		5	6, 600	15, 800	80, 000	Weld	41. 7	....	....	152. 7
234		5	9, 000	17, 400	88, 640	Qr. W......	51. 7	....	....	168. 2
Av.	......	....	**6,600**	**16,933**	**86,100**	....	**39.1**	....	**10,343**	**163.7**
235	⅝	5	5, 600	25, 000	84, 170	Qr. W......	22. 4	....	....	157. 0
		5	6, 000	25, 800	86, 868	Qr. W......	19. 4	....	....	162. 0
Av.	......	....	**5,800**	**25,400**	**85,519**	....	**20.9**	....	**15,924**	**159.5**

Strength of chain cables, &c.—Continued.

IRON F (THIRD LOT)—Continued.

SHORT SECTIONS OF CABLE-LINKS, FROM BARS NOS. 679 TO 704 AND 735 TO 752.

Test number.	Diameter of bar.	Number of links in test.	Stress in pounds. First stretch was observed.	Stress in pounds. Fracture took place.	Stress in pounds. Borne by end per square inch sectional area.	Location of fractures.	Ratio between first stretch and fracture.	Stretch of unbroken links.	Strength of bars.	Strength of links in per cent. of bars.
	″							″		
236	¾	5	10, 000	38, 000	81, 540	Qr. W……	26. 3	……	……	165. 0
237		5	10, 000	31 400	67, 380	Weld……	31. 8	……	……	136. 3
Av.	……	……	10,000	34,700	74,460	……	29.0	……	23,024	150.6
238	⅞	5	17, 600	44, 000	71, 035	End lk……	……	……	……	140. 5
239		4	14, 010	48, 800	78, 964	End lk……	……	……	……	155. 7
Av.	……	……	15,805	46,400	74,999	……	……	……	31,317	148.1

IRON Fx (LOT No. 1).

SHORT SECTIONS OF CABLE-LINKS FROM BARS NOS. 753 TO 797.

240	1	3	34, 800	70, 300	86, 036	Qr. W……	49. 5	1. 12	45,040	156.8
241	1⅛	3	44, 400	81, 400	79, 725	Thro. W …	54. 5	1. 42	57,620	141.2
242	1¼	3	61, 100	111, 000	90, 464	Qr. B ……	55. 0	1. 70	68,460	162.0
243	1⅜	3	78, 000	124, 000	82, 887	Weld ……	62. 9	2. 25	80,360	154.2
244	1½	3	80, 000	153, 000	88, 593	Qr. W……	52. 3	2. 15	94,520	161.8
245	1⅝	3	98, 000	168, 000	81, 513	Qr. W……	58. 3	3. 11	110,140	152.4
246	1¾	3	100, 000	185, 000	76, 923	Qr. W……	54. 0	2. 60	129,500	142.8
247	1⅞	3	110, 800	205, 600	74, 063	Thro. W …	53. 9	2. 90	146,780	140.0
248	2	3	117, 200	240, 000	76, 384	Not broken	……	4. 80	163,420	……

THIRD LOT FROM BARS NOS. 825 TO 842.

249	1	4	34, 590	69, 600	88, 617	Thro. W …	49. 6	……	42,350	164.4
250	1⅛	4	39, 600	86, 000	85, 724	Thro. W …	46. 0	……	54,800	157.0
251	1¼	4	49, 000	105, 000	84, 202	Thro. W …	46. 7	……	66,400	158.0
252	1⅜	4	60, 000	126, 800	83, 586	Qr. W……	47. 3	……	80,000	158.6
253	1½	4	70, 600	152, 800	85, 815	Qr. W……	46. 2	……	94,600	161.6
254	1⅝	3	83, 000	179, 000	85, 769	Qr. W……	46. 4	……	111,300	160.8
255	1¾	3	100, 000	190, 600	80, 237	Thro. W …	52. 5	……	126,100	151.2
256	1⅞	2	109, 000	229, 000	83, 394	Thro. W …	47. 6	……	146,500	156.4
257	2	2	118, 000	238, 600	75, 938	Thro. W …	49. 5	……	159,500	149.6

Strength of chain cables, &c.—Continued.

IRON G.

SINGLE LINKS FROM BARS NOS. 205 TO 228.

Test number.	Diameter of bar.	Stress at—		Location of fracture.	Strength of bars.	Strength of links in per cent. of bars.
		First stretch.	Fracture.			
	″					
258	$1\frac{7}{16}$	155,100	95,564	Qr. W	86,400	179.6
259	$1\frac{1}{2}$	160,100	90,605	Qr. W	91,800	174.4
260	$1\frac{5}{8}$	195,200	94,118	End lk	106,200	183.2
261	$1\frac{11}{16}$	198,000	88,550	Qr. W	115,800	171.0
262	$1\frac{3}{4}$	215,200	89,480	Qr. W	121,200	177.6
263	$1\frac{13}{16}$	223,300	86,550	Qr. W	129,800	172.0

IRON H.

SINGLE LINKS FROM BARS NOS. 229 TO 240.

264	$1\frac{1}{2}$	170,000	96,208	Qr. W	92,700	183.4
265	$1\frac{5}{8}$	204,100	97,409	Qr. W	108,500	188.0
266	$1\frac{3}{4}$	225,200	98,638	Qr. W	129,400	174.0

IRON J.

SINGLE LINKS FROM BARS NOS. 256 TO 281.

267	$1\frac{7}{16}$	153,600	94,659	Qr. W	81,800	187.8
268	$1\frac{1}{2}$	157,600	89,190	Qr. W	90,200	174.6
269	$1\frac{5}{8}$	120,000	57,859	Qr. W	109,400	109.6
270	$1\frac{11}{16}$	211,600	94,633	Qr. W	121,000	174.8
271	$1\frac{3}{4}$	222,700	92,600	Qr. W	128,100	173.8
272	$1\frac{13}{16}$	195,800	75,891	Qr. W	126,300	155.0

IRON L.

SINGLE LINKS FROM BARS NOS. 282 TO 305.

273	$1\frac{7}{16}$	138,600	85,397	Qr. W	112,230	123.4
274	$1\frac{1}{2}$	193,200	109,337	Qr. W	123,300	156.6
275	$1\frac{5}{8}$	163,600	78,861	Qr. W	139,200	116.2
276	$1\frac{11}{16}$	222,900	99,642	Qr. W	123,700	180.0
277	$1\frac{3}{4}$	254,600	105,862	Qr. W	145,000	175.6
278	$1\frac{13}{16}$	232,000	89,922	Qr. W	145,000	160.0

Strength of chain cables, &c.—Continued.

IRON K.

SHORT SECTIONS OF CABLE-LINKS FROM BARS NOS. 849 TO 868.

Test number.	Diameter of bars.	Number of links in test.	Stress in pounds.			Location of fracture.	Ratio between first stretch and fracture.	Stretch of unbroken links.	Strength of bar.	Strength of links in per cent. of links.
			First stretch was observed.	Fracture took place.	Borne by end per square inch sectional area.					
	"							"		
279	$1\frac{1}{8}$	2	39,400	84,500	85,001	Qr. W	46.6	1.70	60,096	140.6
280	$1\frac{1}{4}$	2	47,000	96,000	78,240	Weld	49.0	.50	72,960	131.4
281	$1\frac{3}{8}$	2	58,000	125,800	84,714	Qr. W	42.2	.47	82,848	150.6
282	$1\frac{1}{2}$	2	57,600	143,000	80,925	Qr. W	31.2	.87	101,280	141.2
383	$1\frac{5}{8}$	2	69,000	171,000	82,449	Qr. W	40.4	.87	....	....
284		2	76,800	183,900	88,669	Qr. W	41.7	.85	....	....
Av.	......	....	72,900	177,450	85,559	....	41.0	.86	118,463	149.7
285	$1\frac{3}{4}$	2	72,500	172,800	71,850	Qr. W	42.0	.65	139,200	....
286	$1\frac{7}{8}$	2	97,000	246,800	89,887	T. W	39.0	1.00	154,080	160.0
287	2	2	104,000	258,900	82,400	Qr. W	40.0	1.00	191,520	135.2

SINGLE LINKS FROM SAME BARS.

Test number.	Diameter of bars.	Number of links in test.	First stretch was observed.	Fracture took place.	Borne by end per square inch sectional area.	Location of fracture.	Ratio between first stretch and fracture.	Stretch of unbroken links.	Strength of bar.	Strength of links in per cent. of links.
288	$1\frac{1}{8}$	1	39,900	100,400	101,006	Qr. W	39.6	....	....	167.2
289		1	40,300	92,200	92,756	Qr. W	43.7	....	....	158.4
Av.	......		40,100	96,300	96,878	....	41.6	....	60,096	160.2
290	$1\frac{1}{4}$	1	58,600	128,600	104,808	Qr. W	45.6	....	....	176.2
291		1	66,200	123,800	100,896	Qr. W	53.5	....	....	169.6
Av.	......		62,400	126,200	102,852	....	49.5	....	72,960	172.9
202	$1\frac{3}{8}$	1	57,600	137,200	92,390	Qr. W	42.0	....	....	165.6
293		1	53,800	126,700	85,320	Side	42.5	....	....	153.0
Av.	......		55,700	131,950	88,855	....	42.3	....	82,848	159.3
294	$1\frac{7}{16}$	1	....	178,000	109,673	Qr. W	....	....	99,300	179.2
295	$1\frac{1}{2}$	1	57,600	146,900	83,135	Qr. W	39.2	....	....	145.0
296		1	....	184,700	104,527	Qr. W	....	....	....	182.0
Av.	......		57,600	165,800	93,831	....	39.2	....	101,280	163.5
297	$1\frac{5}{8}$	1	72,000	202,200	97,492	Qr. B	35.6	....	....	170.6
298		1	72,000	163,200	78,688	Qr. W	44.1	....	....	137.8
299		1	....	215,400	103,857	Qr. W	....	....	....	181.8
Av.	......		72,000	193,600	93,346	....	39.8	....	118,463	166.7
300	$1\frac{11}{16}$	1	....	233,800	104,561	Qr. W	....	....	....	179.5
301		1	....	219,300	98,077	Qr. B	....	....	....	168.7
Av.	......		....	226,550	101,319	....	....	....	130,000	174.1
302	$1\frac{3}{4}$	1	....	241,500	100,415	Qr. W	....	....	139,200	173.4
303	$1\frac{7}{8}$	1	97,000	263,000	95,256	Qr. B	36.9	....	....	170.6
304		1	105,600	264,000	95,617	Qr. B	40.0	....	....	171.4
Av.	......		101,300	263,500	95,436	....	38.5	....	154,080	171.0

Strength of chain-cables, &c.—Continued.

IRON N.

SHORT SECTIONS OF CABLE LINKS FROM BARS NOS. 896 TO 911.

Test number.	Diameter of bar.	Number of links in test.	Stress in pounds.			Location of fracture.	Ratio between first stretch and fracture.	Stretch of unbroken links.	Strength of bars.	Strength of links in per cent. of bars.
			First stretch was observed.	Fracture took place.	Borne by and per square inch sectional area.					
	"									
305	1⅛	4	45,000	85,000	84,915	Thro. W...	53.0	1.76	56,200	151.9
306	1¼	4	58,000	105,000	85,574	Qr. W	58.8	2.06	69,300	151.6
307	1⅜	4	70,100	126,400	84,492	Qr. W	55.4	2.52	81,200	155.4
308	1½	4	80,000	152,200	87,270	Qr. W	52.5	2.77	93,400	162.8
309	1⅝	4	96,200	195,500	92,566	Qr. W	49.2	3.60	119,000	164.2
310	1¾	4	110,300	201,100	85,538	Qr. W	54.8	1.75	129,350	161.8
311	1⅞	4	116,200	223,700	81,463	Qr. W	51.9	3.40	140,150	159.6
312	2	4	118,000	232,000	73,116	Thro. W...	50.8	2.60	164,200	141.2

IRON O.

SHORT SECTIONS FROM BARS NOS. 912 TO 920.

313	1	3	31,400	68,000	84,872	Qr. W	46.2	....	46,000	148.0
314	1⅛	3	35,000	80,900	85,131	Qr. W	63.3	....	50,400	160.6
315	1¼	3	45,800	95,500	77,832	Thro. W...	48.0	....	61,400	155.6
316	1⅜	3	51,200	125,400	87,631	Qr. W	40.8	....	72,400	173.2
317	1½	3	60,000	155,500	86,823	Qr. B......	38.6	....	91,400	170.0
318	1⅝	3	74,500	180,000	87,336	Qr. B......	41.4	....	108,000	166.6
319	1¾	3	90,000	207,000	89,070	Qr. W	43,5	....	116,500	177.6
320	1⅞	3	102,000	237,000	87,288	Qr. B......	43.0	....	129,000	183.8
321	2	3	119,800	238,000	75,747	Weld	50.8	....	151,600	156.0

Strength of chain cables, &c.—Continued.

IRON P.

SHORT SECTIONS FROM BARS NOS. 921 TO 925.

Test number.	Diameter of bar.	Number of links in test.	Stress in pounds. First stretch was observed.	Stress in pounds. Fracture took place.	Stress in pounds. Borne by end per square inch sectional area.	Location of fracture.	Ratio between first stretch and fracture.	Stretch of unbroken links.	Strength of bars.	Strength of links in per cent. of bars.
	"									
322	1¼	2	42,240	117,120	91,002	Weld	36.0	....	....	
		2	....	107,520	86,222	Qr. W......	....	....	....	
Av.		....	....	112,320	88,612	....	....	....	70,404	158.8
323	1 5/16	3	55,000	110,500	81,670	Qr. B	49.7	....	....	
324		3	52,000	109,500	80,931	Thro. B....	45.7	....	....	
325		3	55,000	111,500	82,409	Qr. W	49.3	....	....	
326		3	....	110,000	81,300	Thro. B....	....	....	....	
327		6	50,000	109,000	80,561	Qr. W......	45.8	....	....	
328		3	52,000	109,500	80,931	Qr. W......	47.5	....	....	
Av.			52,800	110,000	91,317	....	47.6	....	74,490	141.4
329	1⅜	2	....	134,592	89,968	Qr. W......	....	....	78,624	170.1
330	1 7/16	3	60,600	141,000	86,876	Qr. B	43.2	....	....	
331		3	60.600	141,200	86,999	Qr, B	42.9	....	....	
332		3	58,900	141,000	86,876	Qr. B	41.7	....	....	
333		3	63,500	139,400	85,890	Qr. B	45.5	....	....	
334		3	65,000	142,500	87,800	Qr. B	45.5	....	....	
335		3	61,800	140,900	86,814	Qr. B	43.8	....	....	
Av.	......	....	61,800	141,000	86,876	....	43.8	....	89,300	157.9
336	1½	2	....	134,592	74,196	Qr. W......	....	....	95,904	140.3
337	2	2	125,000	256,320	80,000	Thro. W ...	48.8	....	159,840	160.3

SECOND LOT—BARS NOS. 926 TO 942.

Test number.	Diameter of bar.	Number of links in test.	First stretch was observed.	Fracture took place.	Borne by end per square inch sectional area.	Location of fracture.	Ratio between first stretch and fracture.	Stretch of unbroken links.	Strength of bars.	Strength of links in per cent. of bars.
338	1	3	38,000	60,400	78,461	Qr. W......	62.9	....	44,500	135.8
339	1⅛	3	45,200	76,000	77,141	Qr. W......	59.5	....	56,500	
340	1¼	3	50,400	122,100	94,871	Thro. W ...	43.1	....	73,200	166.8
341	1⅜	3	60,000	118,4(0	76,933	End lk.....	50.7	....	85,000	139.6
342	1½	3	73,600	156,000	85,950	Qr. W......	47.2	....	98,300	158.6
343	1⅝	3	86,000	199,000	94,270	Qr. B	43.2	....	117,500	169.4
344	1¾	3	106,000	212,000	88,143	End lk.....	50.0	....	130,050	163.0
345	1⅞	3	115,000	238,000	83,933	Qr. B	49.4	....	145,200	160.4
346	2	3	129,000	242,000	....	Not broke .	....	....	161,300	

THIRD LOT (P*x*)—BARS NOS. 943 TO 952.

Test number.	Diameter of bar.	Number of links in test.	First stretch was observed.	Fracture took place.	Borne by end per square inch sectional area.	Location of fracture.	Ratio between first stretch and fracture.	Stretch of unbroken links.	Strength of bars.	Strength of links in per cent. of bars.
347	1¼	4	53,000	116,000	93,023	Thro. W ...	45.7	....	70,250	165.2
348	1½	4	71,400	156,000	87,102	Thro. W ...	45.8	....	97,250	160.2
349	1¾	3	98,000	209,800	86,231	Qr. W......	46.7	....	131,900	158.4
350	1⅝	3	84,600	196,200	91,003	Qr. B	43.1	....	115,500	169.9
351	1⅞	2	108,200	236,000	85,943	Thro. W ...	45.8	....	142,000	166.2

Strength of chain cables, &c.—Continued.

IRON M.

SHORT SECTIONS OF CABLE-LINKS FROM BARS NOS. 1087 TO 1408.

Test number.	Diameter of bar.	Number of links in test.	Stress in pounds.			Location of fracture.	Ratio between first stretch and fracture.	Numbers of bar tests in the averages.	Strength of bars.	Strength of links in per cent. of bars.
			First stretch was observed.	Fracture took place.	Borne by end per square inch sectional area.					
	"									
352	1¼	3	48,700	119,000	96,984	B	40.9			180.4
353		3	52,000	112,500	91,687	B	46.2			170.6
354		3	51,800	123,500	100,652	Qr. B	41.9			187.2
355		3	56,000	119,800	97,636	Qr. W	46.8			181.6
356		3	56,700	112,000	91,279	B	50.6			169.8
357		3	57,000	119,500	97,892	Qr. W	47.7			181.2
Av.			**53,700**	**117,716**	**98,905**		**45.7**	1087 to 1106	**65,960**	**178.4**
358	1⅜	3	56,000	126,000	84,962	Qr. B	44.4			156.0
359		3	56,500	120,500	81,254	Qr. W	46.8			149.4
360		3	55,000	121,000	81,591	Qr. B	45.4			149.8
361		3	56,800	125,000	84,288	Qr. B	45.4			154.8
362		3	52,400	122,500	82,602	Qr. B	42.8			151.8
363		3	63,000	122,000	82,269	Qr. W	51.6			151.2
Av.			**56,617**	**122,833**	**82,827**		**46.1**	1107 to 1134	**80,693**	**152.1**
364	1⅜	3	53,000	125,000	84,803	Thro. W	42.4			143.8
365		3	53,200	136,600	92,673	Thro. W	38.9			157.2
366		3	52,300	115,000	78,019	Thro. W	45.5			132.4
367		3	53,600	119,000	80,732	Thro. W	45.0			137.0
368		3	58,000	111,000	75,305	Thro. W	52.2			137.8
Av.			**54,020**	**121,320**	**82,306**		**44.8**	1135 to 1182	**86,862**	**141.6**
369	1⅜	3	56,000	106,000	71,253	Thro. W	52.8			135.6
370		3	60,000	96,000	65,130	Thro. W	62.5			122.8
371		3	59,500	103,400	70,511	Thro. W	57.5			132.2
372		3	56,200	95,800	64,104	Thro. W	58.6			122.6
373		3	55,400	105,800	71,795	Thro. W	52.3			135.4
374		3	59,000	111,000	75,305	Thro. W	53.1			142.0
Av.			**57,683**	**103,000**	**69,683**		**56.1**	1183 to 1186	**78,150**	**131.8**
375	1⅜	3	70,000	132,000	87,013	Thro. W	53.0			150.8
376		3	73,000	127,600	83,454	Thro. W	57.2			146.0
377		3	67,600	115,600	76,203	Thro. W	58.5			132.0
378		3	70,000	95,000	62,628	Thro. W	73.7			108.4
379		3	65,600	126,600	83,454	Thro. W	51.8			144.6
Av.			**69,240**	**119,360**	**78,549**		**58.8**	1187 to 1221	**87,496**	**136.3**
380	1½	3	69,000	151,600	85,800	Qr. W	45.5			155.9
381		3	70,000	143,900	81,430	Thro. W	48.6			148.0
382		3	73,200	155,300	87,880	Qr. W	47.1			159.7
383		3	72,600	161,000	91,110	Qr. W	45.1			165.5
384		3	72,600	151,000	85,400	Qr. W	48.1			162.8
385		3	74,500	152,000	86,000	Qr. W	49.0			163.8
Av.			**71,700**	**152,467**	**86,270**		**47.2**	1222 to 1385	**97,601**	**159.3**
386	1½	3	60,000	155,000	87,719	Thro. W				151.7
387		3	80,000	140,000	79,230	Thro. W				137.0
Av.			**70,000**	**147,500**	**83,474**			1386 to 1397	**102,125**	**144.3**
388	1⅝	3	80,000	125,000	60,270	Thro. W	64.0			104.4
389		3	79,000	180,000	86,788	Thro. W	43.7			150.3
Av.			**79,500**					1398 to 1408	**119,804**	

Strength of chain cables, &c.—Continued.

IRON M—Continued.

SINGLE CABLE LINKS FROM THE SAME BARS.

Test number.	Diameter of bar.	Stress in pounds.			Location of fracture.	Ratio between first stretch and fracture.	Numbers of bar tests in the averages.	Strength of bar.	Strength of links in per cent. of bars.
		First stretch was observed.	Fracture took place.	Borne by end per square inch, sectional area.					
	″								
390	1¼	50,500	125,500	102,282	Qr. B......	40.2	....	....	190.2
391		62,500	128,500	100,652	Qr. W.....	50.6	....	....	187.2
392		63,400	122,000	99,429	Qr. W.....	51.9	....	....	185.0
Av.	......	58,800	123,670	100,788	....	47.6	1087 to 1106	65,960	185.4
393	1⅜	57,900	130,000	87,660	Qr. W.....	44.5	....	....	161.2
394		63,000	113,000	76,196	Side	55.8	....	....	140.0
395		71,000	134,400	90,627	Weld	52.8	....	....	166.6
Av.	......	63,967	125,800	84,828	....	51.0	1107 to 1134	80,693	155.9
396	1⅜	56,000	139,500	94,640	Qr. W.....	40.1	....	....	160.6
397		57,900	135,000	91,587	Qr. W.....	42.9	....	....	155.4
398		58,000	132,000	89,552	Qr. W.....	44.0	....	....	151.8
399		58,700	133,500	90,569	Qr. W....	43.9	....	....	153.6
Av.	......	57,650	135,000	91,587	....	42.7	1135 to 1182	86,862	155.3
400	1⅜	67,000	116,000	78,690	Thro. W ..	57.7	....	....	148.4
401		69,000	113,300	76,865	Thro. W ..	60.9	....	....	145.0
402		65,000	112,100	76,051	Thro. W ..	57.9	....	....	143.4
Av.	......	67,000	113,800	77,202	....	58.8	1183 to 1186	78,150	145.6
403	1⅜	98,600	135,600	89,836	Thro. W ..	72.7	....	....	154.8
404		75,000	141,000	92,940	Thro. W ..	68.2	....	....	161.0
405		90,000	105,000	69,218	Thro. W ..	85.7	....	....	120.0
406		85,600	136,000	89,650	Thro. W ..	72.9	....	....	155.4
407		83,000	125,600	82,729	Thro. W ..	66.1	....	....	143.4
Av.	......	86,550	128,640	84,874	....	70.1	1187 to 1221	87,496	146.9
408	1½	89,600	160,000	90,545	End lk....	56.0	....	....	164.5
409		95,600	155,600	88,050	Thro. W ..	61.4	....	....	160.0
410		88,600	147,600	83,530	Qr. W.....	60.0	....	....	151.7
Av.	......	90,933	154,400	87,375	....	59.1	1222 to 1385	97,601	158.7
411	1½	81,000	175,000	99,037	T. W......	46.2	....	....	171.3
412		90,000	173,000	97,906	Qr. W.....	52.0	....	....	179.2
Av.	......	85,500	174,000	98,471	....	49.1	1386 to 1397	102,125	175.2
413	1⅝	65,200	135,000	65,000	Thro. W ..	48.5	....	....	112.7
414		60,000	182,500	88,000	Qr. W.....	37.8	....	....	152.4
Av.	......	67,100	158,750	76,500	....	48.1	1398 to 1408	119,800	132.5

Strength of chain cables, &c.—Continued.

IRON M—Continued.

[Record furnished by Bureau of Equipment.]

SHORT SECTIONS OF CABLE LINKS, ROUND BARS.

Test number.	Diameter of bars.	Number of links in test.	Stress in pounds.		Location of fracture.	Strength of bars.	Strength per square inch original area.	Number of bar tests in the averages.	Strength of links in per cent. of bars.
			Fracture took place.	Borne by end per square inch sectional area.					
415	″ 1¼	3	92,000	75,244	Thro. W				126.6
416		3	112,000	91,279	Qr. W				154.0
417		3	101,000	82,314	W				138.9
418		3	114,000	92,909	Qr. W				156.8
419		3	102,000	83,129	W				140.3
Av.			101,200			72,700	59,248	53	143.3
420	1$\frac{5}{16}$	3	77,000	57,650	Thro. W				100.3
421		3	117,000	86,474	Qr. W				152.3
422		3	115,000	85,070	Thro. W				149.8
423		3	92,000	67,977	Thro. W				119.8
Av.						76,800	56,761	20	130.7
424	1⅜	3	133,000	89,562	Qr. W				157.7
425		3	126,800	85,387	Thro. W				150.4
426		3	113,100	76,094	Thro. W				134.0
Av.			124,300			84,300	56,777	18	147.7
427	1½	3	158,000	89,417	Thro. W				158.9
428		3	169,000	95,642	Thro. W				169.9
429		3	162,000	91,680	Thro. W				162.9
430		3	158,600	89,756	Qr. W				159.5
431		3	155,600	88,058	Thro. W				156.4
Av.						99,429	56,270	47	160.7
432	1⅝	3	187,000	90,175	Qr. W	113,760	54,851	5	164.4
433	1$\frac{11}{16}$	3	207,000	92,576	Thro. W	127,700	57,115	5	162.1
434	1¾	3	223,000	92,723	B				162.7
435		3	225,600	93,804	Qr. W				164.5
436		3	213,000	88,565	Qr. W				155.3
437		3	215,600	89,646	Qr. B.				157.3
438		3	212,000	88,149	Thro. W				154.7
Av.						137,092	57,003	29	158.9
439	1$\frac{13}{16}$	3	222,000	86,046	Thro. W				162.9
440		3	210,000	81,395	Thro. W				147.6
441		3	222,000	86,046	Thro. W				162.9
442		3	228,600	88,605	Thro. W				167.6
Av.						142,367	55,181	24	160.2
443	2	3	278,000	91,661	Side				162.1
444		3	276,000	91,024	Qr. W				160.9
445		3	255,000	81,158	Side				148.6
Av.						171,490	54,580	47	167.2

The tests in detail of the individual bars was not furnished.

Strength of chain cables, &c.—Continued.

IRON M—Continued.

SINGLE LINKS FROM THE SAME BARS.

Test number.	Diameter of bar.	Number of links in test.	Stress in pounds.		Location of fracture.	Strength of bar.	Strength per square inch original area.	Number of bar tests in the averages.	Strength of links in per cent. of bars.
			Fracture took place.	Borne by end per square inch sectional area.					
	"								
446	1¼	......	115, 800	94, 376	Thro. W	......	......	......	159. 3
447		......	121, 000	98, 614	Thro. W	......	......	......	166. 4
448		......	111, 000	90, 464	Thro. W	......	......	......	152. 7
449		......	124, 800	101, 711	Qr. W	......	......	......	171. 7
450		......	110, 400	89, 975	E. lk	......	......	......	151. 9
Av.	......	......	**116,600**	**95,028**	......	**72,700**	**59,248**	**53**	**160.5**
451	1 5/16	......	133, 000	98, 300	Thro. W	......	......	......	173. 1
452		......	130, 000	96, 082	Thro. W	......	......	......	169. 3
453		......	128, 000	94, 604	Thro. W	......	......	......	166. 7
454		......	110, 000	81, 300	Thro. W	......	......	......	143. 2
Av.	......	......	**125,250**	**92,571**	......	**76,800**	**56,761**	**20**	**163.1**
455	1⅜	......	115, 000	77, 441	Thro. W	......	......	......	136. 4
456		......	139, 600	94, 007	Thro. W	......	......	......	165. 6
457		......	133, 000	89, 562	Thro. W	......	......	......	157. 7
458		......	127, 600	85, 926	Qr. W	......	......	......	151. 3
Av.	......	......	**128,800**	**86,734**	......	**84,300**	**56,777**	**18**	**152.7**
459	1½	......	174, 000	98, 472	E. lk	......	......	......	175. 0
460		......	161, 000	91, 114	Thro. W	......	......	......	162. 0
461		......	153, 000	86, 587	Thro. W	......	......	......	153. 9
462		......	165, 600	93, 718	Qr. B	......	......	......	166. 6
463		......	173, 000	97, 906	Qr. W	......	......	......	174. 0
464		......	165, 600	93, 718	Thro. W	......	......	......	166. 6
465		......	168, 600	95, 416	Qr. W	......	......	......	169. 5
Av.	......	......	**165,828**	**93,847**	......	**99,429**	**56,270**	**47**	**166.8**
466	**1⅝**	......	**198, 000**	**93, 057**	Qr. W	**113,760**	**54,851**	**5**	**169.6**
467	**1 11/16**	......	**207, 000**	**92, 576**	E. lk	**127,700**	**57,115**	**5**	**162.1**
468	1¾	......	235, 600	97, 962	Qr. W	......	......	......	171. 9
469		......	235, 000	97, 709	Thro. W	......	......	......	171. 4
470		......	200, 000	83, 160	Thro. W	......	......	......	145. 9
471		......	193, 000	80, 274	Thro. W	......	......	......	140. 7
472		......	198, 600	82, 578	Thro. W	......	......	......	144. 8
Av.	......	......	**212,440**	**88,336**	......	**137,092**	**57,003**	**29**	**154.9**
473	1 13/16	......	210, 000	81, 395	Thro. W	......	......	......	147. 6
474		......	225, 600	87, 441	Thro. W	......	......	......	166. 2
475		......	243, 000	94, 186	Thro. W	......	......	......	170. 7
476		......	240, 000	96, 511	Thro. W	......	......	......	174. 9
Av.	......	......	**231,900**	**89,883**	......	**142,367**	**55,181**	**24**	**164.8**

Strength of chain cables, &c., and of round-bars made of iron rolled at Washington Navy Yard.

SHORT SECTIONS FROM ROUND BARS AS GIVEN.

Test number.	Diameter of bar.	Strength of link.	Location of fracture.	Elastic limit per square inch.	Strength of bars.		Strength of link in per cent. of bars.
					Observed.	Per square inch.	
	″						
477	1	67,600	Qr. W		45,000	56,166	151.6
478		69,400	Qr. W		44,400	56,532	154.7
479		69,400	Qr. W		44,400	56,532	154.7
Av.		**68,800**		**39.890**	**44,600**	**56,410**	153.7
480	1¼ (1.26)	108,000	Qr. W		68,000	54,535	160.4
481		115,000	Qr. W		67,000	53,733	170.8
482		108,600	Qr. B		67,000	53,733	161.3
Av,		**110,533**		**38,320**	**67,333**	**54,000**	163.9
483	1⅜ (1.38)	134,800	Qr. W		84,000	56,161	162.8
484		135,000	Thro. W		82,000	54,824	162.0
485		137,400	Qr. W		82,600	55,225	165.8
Av.		**135,900**		**37,000**	**82,867**	**55,403**	**163.8**
486	1½ (1.49)	150,000	Qr. W		92,600	53,105	161.8
487		149,000	Qr. W		92,000	52,761	160.7
488		151,000	Qr. W		93,600	53,671	162.8
Av.		**150,000**		**29,800**	**92,733**	**53,179**	**161.8**
489	1 9/16 (1.59)	163,000	Qr. W		108,600	54,596	151.7
490		176,800	Qr. W		106,200	53,485	161.3
491		158,000	Qr. W		107,600	54,193	147.0
Av.		**165,867**		**35,300**	**107,467**	**54,123**	**154.3**
492	1⅝ (1.63)	179,800	Qr. W		110,400	52,899	161.4
493		178,000	Qr. W		111,400	53,378	159.8
494		178,600	Qr. W		112,400	53,857	160.3
Av.		**178,800**		**36,100**	**111,400**	**53,378**	**160.5**
495	1¾ (1.77)	**204,000**	Qr. W	**36,400**	**128,500**	**52,214**	**158.8**
496	2 (2.02)	260,000	Qr. W		173,000	53,983	153.1
497		268,600	Qr. W		167,600	52,298	158.1
498		258,600	Qr. B		169,000	52,922	152.2
Av.		**262,400**			**169,867**	**53,068**	**154.5**

NOTE.—This set of tests was made at the navy-yard, Washington, by the officers in charge of the Equipment Department. The Board has been permitted by the Chief of the Bureau of Equipment to make use of these tests, which are taken at random from the voluminous records which have been kept. Since the results obtained by the manufacture in 1875 of the experimental cable (Iron A), demonstrated that the scrap heaps of the various yards contained ample material which by suitable work could be transformed into excellent chain iron at slight cost, trains of rolls having succeeded those of the copper mill, where Iron A was produced, every bar rolled is expected to withstand the most severe tests for ductility.

PART II, SECTION II.

PROOF STRAINS FOR CHAIN CABLES.

EFFECTS BY THE USE OF THE STRAINS PRESCRIBED BY THE ADMIRALTY PROOF TABLE—DISCUSSION OF THE PRINCIPLES UPON WHICH "PROOF-STRAINS" SHOULD BE BASED—PROOF-TABLE CALCULATED UPON SUCH PRINCIPLES.

A finished cable has yet a final ordeal to undergo before it is issued for service, one which may prove disastrous to its value, even if it has escaped every danger that has accompanied its manufacture. It is to be "proved," which means that each of the fifteen fathom "sections" of which it is composed, is to be subjected to a tensional strain sufficient to make it probable that the presence of any very defective links will be made manifest, that they may be removed and replaced by others.

As tension in excess will probably injure the cable, it becomes a matter of importance to fix upon a strain for each size which, while sufficient to insure the detection of unduly weak links, *will not produce them.* Most American manufacturers of cable, use for each size, a stress which is prescribed by the standard proof-table of the British Admiralty, and their cables are sold with a guarantee that they have been so proved. Our experiments lead us to doubt the wisdom of thus applying this English standard to measure American material. We consider that, as applied to cables made from American bar iron, this standard is faulty in two important respects.

First. The stress prescribed by it for every size of cable is *too great.*

Second. The stresses for the different sizes are unequal in their proportion to the strength of the links.

And we assign the following reasons for these opinions:

First. The stress for all sizes is based upon the assumption that the cable bolts of all diameters possess a strength equal to 60,000 pounds per square inch. Few bars of American iron are equal to this strength, and when they are, their cost precludes their use as cable iron; and as has been shown in the investigations by tension, although this strength may be found in the small bars, it is not found in the large sizes of the same iron.

Secondly. If the bars of all sizes did possess this strenth, the "proof" is still too great, for it probably exceeds by a considerable amount the *elastic limit* of the links.

The table as furnished to the committee by two prominent manufacturers, viz, Messrs. J. B. Carr & Co., of Troy, and Mr. H. L. Fearing, of Boston, is herewith given, that the discussion which follows may be clearly understood.

Columns 1 and 2 are as furnished to us: No. 3 contains the stresses calculated by a formula given.

Size.	Column 1.		Column 2.		Column 3.	
	Stress in—		Stress in—		Stress in—	
	Tons.	Pounds.	Tons.	Pounds.	Tons.	Pounds.
"						
1	18	40,320	18	40,320	18.00	40,320
1 1/16	20	44,800	20	44,800	20.32	45,517
1 1/8	23	51,520	23	51,520	22.78	51,030
1 3/16	26	58,200	25	55,960	25.38	56,857
1 1/4	28	62,720	29	64,960	28.12	63,000
1 5/16	30	67,200	31	69,440	31.01	69,457
1 3/8	34	76,160	34	76,160	34.03	76,230
1 7/16	37	82,880	37	82,880	37.22	83,317
1 1/2	41	91,800	41	91,800	40.50	90,720
1 9/16	44	98,500	43	96,320	43.94	98,437
1 5/8	48	107,520	48	107,520	47.53	106,470
1 11/16	52	116,480	51	114,240	51.25	114,817
1 3/4	56	125,440	56	125,440	55.12	123,480
1 13/16	60	134,400	59	132,160	59.05	132,275
1 7/8	64	143,360	64	143,360	63.38	141,750
1 15/16	68	152,320	68	152,320	67.57	151,357
2	72	161,280	72	161,280	72.00	161,280
2 1/16	....	....	76	171,360	76.59	171,517
2 1/8	80	179,200	81.3	181,120	81.28	182,070
2 3/16	....	....	....	....	86.13	192,937
2 1/4	88	197,120	91.1	204,064	91.11	204,120

The formula upon which column 3 is calculated is one embodied as a rule, as follows:

"For proof of each size, square the number of eighths of an inch in the diameter of the bar and multiply the result by 630," the result being the stress in pounds; thus—

1″, 8 eighths squared = 64, and 64 × 630 = 40,320 pounds,
2″, 16 eighths squared = 256, and 256 × 630 = 161,280 pounds,
1$\frac{1}{16}$″, 8½ eighths squared = 72¾, and 72¾ × 630 = 45,517 pounds,
which are the proof-strains for the above sizes, and all others are calculated by the use of the *same* constant, 630.

If, as has been proved beyond question by bar-tension tests, the different-sized bars of the same iron do not possess strength in the proportion of their areas, the effect upon them of strains which are based upon the assumption that they do, must necessarily be unequal. This table so assumes, and we find that through this assumption those sizes which are the most important, and which have the least proportional strength, viz, the *large sizes*, are by this "proof" strained to a much greater proportion of their actual strength, than are the smaller and less important cables.

For example, assume that two cables, one of 2″ and one of 1″ iron, are to be proved by the Admiralty standard. The first, if made from a fair quality chain-iron, will in the bar form be equal to a tensile strain of not over 52,000 pounds per square inch, which will give to the entire bar a strength of 163,300 pounds. The probable strength of the cable made from this bar will be not over 265,600 pounds (163 per cent. of the bar's strength), and it is very probable that there will be some links which do not exceed 155 per cent., or 252,600 pounds; the Admiralty proof (161,280 pounds) is equal to over 60 per cent. of the greater and nearly 64 per cent. of the lesser strength.

The bars from which the 1″ cable is made will probably be equal to 57,000 pounds per square inch, which will give entire strength 44,770 pounds, and a probable strength of cable of from 73,000 to 69,300 pounds, using the same percentages as with the 2″. The Admiralty proof-strain for 1″ cable is 40,320 pounds, which is 55 per cent. of the greater and 58 per cent. of the lesser strength, which shows that the large cable would be strained from 5 to 6 per cent. of its strength more than the small one.

Our experiments show that the elastic limit of the large bars is generally lower than that of the small ones of the same iron. Hence the irregular effect of the proof-strains becomes a dangerous one.

The practical and actual results which we have found to occur through the use of this table, and which have doubtless occurred with many cables proved by it, but which have *not* been *found*, are that the stress is so great that it always exceeds the elastic limit of the links, and frequently cracks them.

A few such results will be given. Six sections, each 5 fathoms in length, were made up from a good chain-iron; three were of 1½″ and three of 1⅝″; all were "proved" by the Admiralty table, and after proof inspected in the shop; all were "passed" as sound, but upon examination by aid of a magnifying glass *fourteen* of the three hundred and eighty-seven links were found to be cracked.

The following being the history in detail of the experiments:

Experiment No. 1.

MATERIAL, IRON C.

[Size of link, 1⅝"; Admiralty proof, 106,470 lbs.; original length of link, 9"; length after proof, av. 9".41.

Number of links.	Length of section.	Stress at which first stretch took place.	Elongation at stress of— 95,000 pounds.	102,000 pounds.	106,500 pounds.	Remarks.
	Feet.	*Pounds.*	*Inches.*	*Inches.*	*Inches.*	
62	30	64,320	8	10	12.2	Three links cracked, one on the side and two across the weld.
62	30.1	60,480	9.6	12	14.5	Two links cracked across the weld.
62	30.1	54,680	8.4	12	14	Three links cracked across the weld.

Experiment No. 2.

MATERIAL, IRON C.

[Size of link, 1½"; Admiralty proof, 91,800 lbs.; original length of link, 8"; length after proof, av. 8".32.]

Number of links.	Length of section.	Stress at which first stretch took place.	Elongation at stress of— 82,000 pounds.	87,000 pounds.	90,000 pounds.	Remarks.
	Feet.	*Pounds.*	*Inches.*	*Inches.*	*Inches.*	
67	30.2	48,000	12	15	18	Five links cracked on weld end.
67	30.1	48,000	11	17	19	None cracked.
67	30	43,400	9	12	15	One link cracked.

While making the usual tests to destruction upon several other sections of links, the effect of various amounts of stress was measured with results as follows:

Experiment No. 3.

MATERIAL, IRON C.

[Size of link, 1¾"; Admiralty proof, 123,480 pounds; original length of link, 9".75; at proof, Av. 9".90; at fracture, Av. 10".56.]

Number of links.	Stress at first stretch. Amount of stretch.	Stress at first stretch. Pounds.	Stretch at stress of pounds. 105,000. 1.	105,000. 2.	115,000. 1.	115,000. 2.	124,000. 1.	124,000. 2.	135,000. 1.	135,000. 2.	Fracture. 1.	Fracture. 2.	Breaking-strain, in pounds.	Remarks.
3	.16	99,000	.04	.17	.06	.42	.10	.49	.17	.67	.81	....	207,400	
5	.39	98,000	.04	.56	.07	.80	.15	1.06	.20	1.36	.80	....	196,800	
7	.63	103,000	......	......	.06	1.05	.15	1.44	.18	1.93	.85	....	192,000	
3	.13	86,500	.10	.27	.19	.42	.21	.55	.27	.72	.77	....	195,800	
5	.37	101,800	......	......	.07	.60	.15	.82	.18	1.11	......	....	193,000	
10	.81	97,000	.06	1.19	.08	1.79	.12	2.23	.15	2.90	......	....	202,600	
7	....	....	......	......	......	......	......	......	......	......	......	....	212,000	2d pull.
4	....	....	......	......	......	......	......	......	......	......	......	....	225,000	3d pull.
5	.45	95,000	......	......	......	......	......	......	......	......	......	....	176,000	
8	....	....	......	......	......	......	......	......	......	......	......	....	209,000	2d pull.
8	.16	92,000	.05	.24	.08	.43	.13	.63	.16	.83	......	....	171,000	

This lot was so excessively irregular in its strength that its record is of little value, except in showing, in two cases, the elevation of the limit of stress, when a second pull developed increased strength. The links were some of coarse granulous, and others of soft fibrous iron, the former generally breaking through the weld.

The stretch in columns 1 is of a carefully measured link, that in columns 2 over all.

Experiment No. 4.

MATERIAL, IRON B.

[Size of link, $1\frac{3}{8}$"; Admiralty proof, 132,275 pounds; original length of link, 9."8.]

Number of links.	Stress at first stretch.		Stretch at stress of—								Breaking-strain, in pounds.
	Amount of stretch, center link.	Pounds.	115,000 pounds.		125,000 pounds.		135,000 pounds.		145,000 pounds.		
			1.	2.	1.	2.	1.	2.	1.	2.	
3	.03	98,000	.04	.25	.07	.34	.08	.45	.10	.67	225,000
5	.03	89,000	.06	.64	.11	.80	.15	1.11	.21	1.42	203,500
7	.05	105,000	.08	1.00	.09	1.49	.12	1.90	.18	2.36	223,000

The material was of a hard, coarse nature, and the bars had not received sufficient work, and in consequence were not ductile. The average elongation at Admiralty proof was .12", and the proof-strain was equal to 59 per cent. and 65 per cent. of the strength of the strongest and weakest links.

Experiment No. 5.

MATERIAL, IRON B.

[Size of link, $1\frac{1}{4}$"; Admiralty proof, 114,240 pounds; original length of link, 9".]

Number of links.	Stress at first stretch.		Stretch at stress of pounds.												Breaking-strain, in pounds.
	Amount of stretch in center link.	Pounds.	76,800.		86,400.		96,000.		105,600.		115,200.		124,800.		
			1.	2.	1.	2.	1.	2.	1.	2.	1.	2.	1.	2.	
2	.03	67,200	.04	.08	.06	.12	.11	.22	.16	.31	.25	.50	......	......	202,600
2	.03	73,600	.05	.09	.07	.15	.11	.21	.16	.32	.23	.46	......	......	190,000
2	.03	68,600	.05	.09	.08	.16	.12	.23	.17	.35	.25	.50	......	......	214,000
2	......	71,000	.02	.04	.05	.11	.08	.15	.13	.25	.18	.36	......	......	204,500
3	.03	90,200	......	......	......	......	.04	.26	.07	.38	.14	.58	.18	.84	204,500
5	.03	92,160	......	......	......	......	......	......	.05	.54	.10	.85	.12	1.20	197,000
7	.03	94,000	......	......	......	......	......	......	.07	.88	.11	1.28	.16	1.77	196,000

The material was the same as in the previous experiment, but the bars showed evidence of having received more work. At the Admiralty proof-stress the average elongation of the links was nearly .18", and its proportion of the strength of the strongest and weakest sections was 53.3 per cent. and 58 per cent.

Experiment No. 6.

MATERIAL, IRON B.

[Size of link, 1$\frac{7}{16}$″; Admiralty proof, 83,317 pounds; original length of link, 8″.25.]

Number of links.	Stress at first stretch.		Stretch at stress of pounds—								Breaking-strain, in pounds.
	Amount of stretch, center link.	Pounds.	67,200.		76,800.		86,400.		96,000.		
			1.	2.	1.	2.	1.	2.	1.	2.	
3	.03	61,500	.05	.20	.10	.37	.21	.56	.28	.88	145,000
3	.05	63,500	.05	.16	.06	.81	.13	.51	.21	.75	149,000
3	.05	67,200	....	....	.07	.23	.11	.43	.20	.03	157,000
3	.03	74,000	....	....	.05	.29	.10	.36	.12	.65	158,000
3	.05	68,000	....	....	.07	.37	.14	.57	.20	.86	138,000
5	....	75,000	....	....	.06	.26	.09	.88	.17	1.09	131,500
7	.04	62,600	....	....	.07	.80	.15	1.40	.25	2.16	148,000
10	.03	59,500	....	....	.14	1.40	.21	2.17	.31	3.12	13[illegible],500
15	.03	58,500	....	....	.12	1.81	.26	4.01	.28	4.38	137,300
	.09	....	....	....	....	....	....	....	....	....	*132,000
	.05	....	....	....	....	....	....	....	....	....	*147,000

* Second and third pulls on parts of same section.

Material nominally the same as in the previous experiments, Nos. 4 and 5, but it was considered probable that a portion of the 1$\frac{7}{16}$″ bars were not of the same manufacture as the rest, some being hard and brittle, others fibrous, ductile iron. At Admiralty proof the elongation averaged nearly .16″, and its proportion of the strength of the strongest and weakest links was 52½ per cent. and 63 per cent.

Experiment No. 7.

MATERIAL, IRON B.

[Size of link, 1$\frac{7}{16}$″; Admiralty proof, 83,317 pounds; original length of link, 8″.25.]

No. of links.	Stress at first stretch.	Stretch over all at stress of pounds—		Breaking-strain.	No. of links.	Stress at first stretch.	Stretch over all at stress of pounds—		Breaking-strain.
		78,500	85,500				78,500	85,500	
	Pounds.			*Pounds.*		*Pounds.*			*Pounds.*
1	75,300	.06	.13	150,000	2	62,600	.05	.12	154,500
1	76,800	.12	.12	153,000	2	63,300	.09	.13	144,000
1	67,000	.11	.18	162,000	5	68,000	.09	.13	154,000
2	75,000	.06	.12	154,700	5	64,300	.05	.14	143,000

Material the same as in experiments 4, 5, and 6. The average elongation at proof was .13″, and the proof-strains proportion of the strength of the strongest and weakest links was 51.4 per cent. and 58 per cent.

Experiment No. 8.

MATERIAL, IRON E.

Size of link.	Length of link.	Stretch produced in single links at stress of—													Stretch at Admiralty proof.
		48,000 lbs.	52,800 lbs.	57,600 lbs.	62,400 lbs.	67,200 lbs.	72,000 lbs.	86,400 lbs.	96,000 lbs.	105,600 lbs.	115,200 lbs.	124,800 lbs.	134,400 lbs.	146,000 lbs.	
	"														
1⅛	6.4	.07	.10	.16	.21	......	......	......	......	......	......	......	......	......	.10
1¼	7.0	.06	.09	.11	.15	......	......	......	......	......	......	......	......	......	.12
1⅜	8.1	......	......	.06	.10	.15	.16	......	......	......	......	......	......	......	.16
1½	9.0	......	......	......	......	......	......	.07	.11	.16	.22	.30	......	......	.17
1¾	9.9	......	......	......	......	......	......	......	......	.09	.15	.19	.25	......	.18
1⅞	11.0	......	......	......	......	......	......	......	......	.07	.13	.15	.19	.26	.22
1 15/16	11.2	......	......	......	......	......	......	......	......	.07	.09	.12	.16	.22	......

Experiment No. 9.

IRON A, 2″.

[Admiralty proof, 72 tons.]

Eleven sections of this cable, each 15 fathoms long, were measured at stated intervals while being proved. The cable made from this iron was of the best, in its power of resistance to strains of all natures, yet it could not resist without probable injury, the strain of the Admiralty proof, as shown below.

Number of section.	Stress of first stretch.	Permanent elongation at stress of—				Number of section.	Stress of first stretch.	Permanent elongation at stress of—			
		56 tons.	60 tons.	64 tons.	68 tons.			56 tons.	60 tons.	64 tons.	68 tons.
	Pounds.	*Ft. in.*	*Ft. in.*	*Ft. in.*	*Ft. in.*		*Pounds.*	*Ft. in.*	*Ft. in.*	*Ft. in.*	*Ft. in.*
1	....	2 8	3 5			7	....	2 1½	2 6½		
2	....	2 6	3 6			8	....	1 9	2 4½		
3	....	2 6	3 7½			9	104,600	1 9½	2 4¾		
4	....	2 1	2 7½	3 7½	4 8½	10	112,800	2 2½	3		
5	....	2 8½	2 9			11	108,400	2	2 8½		
6	....	2 1½	2 11								

At 60 tons' stress 125 links from different portions of different sections were carefully measured, and had stretched from .13″ to .16″, averaging nearly .15″.

In the test of the fourth section, which at 56 tons had stretched less than either of the preceding, it was determined to carry the proof still farther, and 4 tons of stress were added, which increased the elongation very little (about 24 per cent.); another 4 tons increased it over 70 per cent., and still another added increased the elongation at 56 tons over 130 per cent., which shows that even a slight addition to a stress already too great produces very disproportionate effects.

We did not think it advisable to risk injury to the cable by applying the 4 additional tons necessary to prove it by the Admiralty standard.

In the following table the strength of the strongest and weakest links made from several of the best of the chain-irons we have examined is given, with the ratio borne to such strength by the Admiralty proof-strains for the sizes:

Iron.	Strength of large links.			Admiralty proof percentage of—		Strength of small links.			Admiralty proof percentage of—	
	Size.	Strongest.	Weakest.	Strongest.	Weakest.	Size.	Strongest.	Weakest.	Strongest.	Weakest.
	In.	*Pounds.*	*Pounds.*			*In.*	*Pounds.*	*Pounds.*		
A	2	283,000	248,000	57.0	65.0	1	72,070	69,600	55.5	58
C	1¾	231,300	191,000	53.0	64.0	1⅛	96,960	74,488	52.5	65
D	1⅞	215,000	....	66.0	....	1	79,200	....	51.3	....
F	1⅞	215,600	....	66.0	....	1	67,600	....	59.6	....
N	1⅞	225,700	....	63.3	....	1⅛	85,600	....	60.0	....
O	1⅞	237,000	....	60.0	....	1	68,000	....	59.3	....
P	1⅞	233,000	....	60.8	....	1¼	122,100	....	51.2	....
Average	......	....	....	61.0	64.5	......	....	....	55.6	61.5

Convinced by the evidence which has been given, that proving American cables by this standard was a fruitful source of weakened cables, we were also aware that in recommending that it should be no longer used, we should, if the advice was followed, deprive manufacturers of good cables of a safeguard against competition by those who might, unchecked, use very inferior iron. We have therefore considered it essential that we should provide a substitute which would, in our judgment, prescribe strains which would fully *prove* cables and not be liable to *injure* them. We submit such a table, which is based upon the two principles, that a proof-strain should not greatly exceed the elastic limit, and that the strength of a cable is equal only to that of its weakest link. In the preparation of this table it was first necessary for us to establish within reasonable limits the probable maximum and minimum strength of cables of various sizes, and the elastic limit of the links. Neither of these factors can be fixed definitely; there are many causes which tend to produce great differences both in the strength and elastic limit of links made from the same bar. The most important of these causes is the liability of the welds, which at the best are the weak spots of all links, to lack uniformity, and no rules can be given which will insure uniform work from a number of chain-welders. We were therefore compelled to base our table upon data which, at the best, could be considered as but indicating probabilities. Assuming as a standard of perfection the characteristics of a bar which, when made into a link, should develop twice the original strength of the bar, we considered that the iron which approached most closely and with uniformity this standard was that which should be considered as the most suitable for cables. We have the records of the strains at which a large number of bars in their normal condition were ruptured by tension, and of many sections of cable made from them, which are incorporated in the "Tables of comparative action of bars and links." From these tables we have made the following abstracts, which enable us to arrive at conclusions as to the probable strength of cables made from irons varying in characteristics:

Ratio of strength of sections of links to that of the bar from which they were made.

[Detail by sizes.]

Size in inches.	A.	B.	C.	D.	F 1.	F 3.	Fx 1.	Fx 3.	K.	M.	N.	O.	P 1.	P 2.	Pz.
1	161.6			165		162.4	156.8	164.4				148		135.8	
1⅛	164.9			149	162.8	168.8	141.2	157	140.6		151.2	160.6		134.5	
1¼	173.5			156.3	156.4	166	162	158	131.4	178.4	151.4	155.6	158.8	166.8	165.2
1 5/16													149		
1⅜	170.3			158	154	164.2	154.2	158.6	150.6	140	154.2	178.2	171.2	139.6	
1 7/16		176 4											157.9		
1½	167.5		161.9	170.8	169.2	167.6	161.8	161.6	141.2	157.2	162.8	170	140.4	158.6	160.2
1⅝	155.6		155.5	164.8	162.5	164.6	152.4	160.8	149.7	127.3	164.2	166.6		169.4	169.9
1 11/16		166.7													
1¾	173		153	158.6	166.9	157.8	142.8	151.2	124.1		161.8	177.6		168	158.4
1 13/16		161.7													
1⅞	176			144.2	163.8	148.8	140	156.4	160		159.6	183.8		160.4	
2	170				170.5			149.6	135.2		141.2	156			
	168.9														
	168.1	168.2	156.8	158.3	164	162.5	151.4	157.5	141.6	150.7	155.8	165.7	156.5	153.5	163.9

Ratio of strength of sections of links to that of bars from which they were made.

[Consolidated.]

	A.	B.	C.	D.	F 1.	F 3.	Fx 1.	Fx 3.	K.	M (1¼(.	M (1⅜).	M (1½).	M (1⅝).	N.	O.	P 1.	P 2.	Pz.	Total.
Below 100 per cent																			
100 to 110 per cent																			1
110 to 120 per cent											1								
120 to 130 per cent									1										5
130 to 135 per cent		1							2		3						1		8
135 to 140 per cent			1				1				3	1				1	2		8
140 to 145 per cent				1			2		3		3		1	1					11
145 to 150 per cent		3	1	1		1		1			3	1			1				12
150 to 155 per cent	2	5	2		1		2	1	2		3	1	1	2					22
155 to 160 per cent	2	2	3	3	1	1	1	4	1		3	4		2	2	13	1	2	45
160 to 165 per cent	7	4	4	2	4	3	2	3			3			3	1	1	3		37
165 to 170 per cent	3	5	3		2	3				1		1			2		2	3	25
170 to 175 per cent	8	2		1						1					1	1			14
175 to 180 per cent	4	7			1														13
180 to 185 per cent		4								3									8
185 to 190 per cent										1									1
	26	34	14	8	9	8	8	9	9	6	22	8	2	8	9	16	9	5	210

Ratio of strength of single links to that of the bars from which they were made.

[Detail by sizes.]

Size in inches.	A.	B.	C 1.	C 2.	D.	E 1.	E 2.	F 1.	G.	H.	J.	K.	L.	M.	P.
1	172.5														
1⅛	176.5			178.2	176.3		158.9	163				160.3			
1¼	168.4			173.6	181		169.1	175.8				172.9		185.4	178.4
1 5/16															160
1⅜	170.8			163.4	175.7		170.2	176.2				159.3		149.9	
1 7/16		177.2	178			185.6			179.6		187.8	170.2	123.4		
1½	172.8		191.4	172.9	193.4	186	164	166	174.4	183.4	174.6	163.5	156.6	171.1	
1⅝	165		189.6	166.4	179.2	187.7	175.1	175.8	183.2	188	109.6	166.7	116.2	137 3	
1 11/16		180.1	177.6			183.2			171		174.8	174.1	180		
1¾	174		199	175.8	182.6	178.4	182.2	172.4	174	176.4	173.8	173.4	175.6		
1 13/16		169	172.8			180.9			172		155		160		
1⅞	179				167.6		163.2	158							
2	181				172										
	173.3	175.4	183.1	171.7	178.5	183.6	168.9	169.6	175.7	182.6	162.6	168.7	152	160.9	169.2

Ratio of strength of single links to that of the bars from which they were made.

[Consolidated.]

	A.	B.	C 1.	C 2.	D.	E 1.	F 1.	G.	H.	J.	K.	L.	M (1¼).	M (1⅜).	M (1½).	M (1⅝).	P.	Total.
Below 110 per cent										1								1
110 to 120 per cent												1		1		1		3
120 to 130 per cent												1						1
130 to 135 per cent																		
135 to 140 per cent											1			1				2
140 to 145 per cent											1			3				4
145 to 150 per cent														1				1
150 to 155 per cent				2		1				1	2			3	1	1		11
155 to 160 per cent						3	1					2		2	1			9
160 to 165 per cent		3		3		4	2							3	1			16
165 to 170 per cent	2	2		5	1	5	1				4			1				21
170 to 175 per cent	6	2	1	7	3	2	2	3	1	3	4				1			35
175 to 180 per cent	2	4	3	7	4	4	4	2			3	2			1		1	37
180 to 185 per cent	1	2		1	2	3		1	1		2		1					14
185 to 190 per cent		1	1			3			1	1			2					9
190 to 195 per cent		1	1		2													4
195 to 200 per cent			1	1														2
	11	15	7	26	12	25	10	6	3	6	17	6	3	15	5	2	1	170

Primarily, we consider that the value of an iron for chain manufacture is not to be measured by the strength of the links, unless this strength is found to be *uniformly maintained*, throughout a series of tests, for we find that those irons which furnished the *strongest* links in nearly every case furnished also the *weakest*, their welding properties being generally defective; for although the portions of the links which have not been subjected to forging are very strong, in each link there is a probable very weak spot caused by a defective weld.

We have the comparative records of 210 sections of cables broken by tension, which were made of fifteen different irons. Assuming that the utmost strength which can be found in a link is equal to 200 per cent. of that of the bar from which it was made, we have a standard by which to compare the irons, and establish their relative value. Examining the abstracts by this standard, we find that 36 sections developed over 170 per cent. of the bar's strength, 22 of them exceeded 175 per cent., 9 exceeded 180 per cent., and 1 only exceeded 185 per cent.

On the other hand, 67 sections developed less than 155 per cent., leaving 107, or over 50 per cent. of the series, which developed between 155 and 170 per cent. of the bar's strength, and of these the average development was 163 per cent.

The 210 sections of various irons can be reduced to 143 sections of iron which may be considered as more or less suitable for cable, by eliminating the records of the 67 sections which were broken at less than 155 per cent of the bar's strength, and at once deciding that they have no claim to be considered as having been made from suitable chain-iron.

This we can do in many cases and assign good reasons; 24 sections were made from an iron (M) in which analysis demonstrated that phosphorus, copper, nickel, and, in some cases, chromium occurred, and possibly reduced their welding values as all the "low breaks" of this iron occurred "through the weld"; 8 were made from iron K, in which carbon was high, and 10 from irons F*x* and P, which were known to have been overworked, leaving but 22 such percentages to be assigned to the chapter of accidents. From which data we conclude that bars of fairly good chain-iron will produce links whose strength will be not less than 155 per cent., and not over 170 per cent., and that by a series of tests, an average of not less than 163 per cent., made up of fairly uniform factors, should be expected. In such a series of tests an occasional "favored" weld may produce an unusually strong link or a defective weld a very weak one. By the record of these the workmanship should be judged, and not the iron, if the records of the other links indicate by their uniformity that the fault is not in the iron.

We have, therefore, adopted for our standard of strength and welding qualities combined, 170 per cent. of the strength of the bar for a maximum, 163 per cent. for an average, and 155 per cent. for a minimum. Iron which in the link form develops the average, by results which do not vary greatly, we consider it to be *suitable;* that which falls below the average or produces it by very irregular factors, we consider as *unsuitable.*

It remains to decide upon the strength of bar, which will most probably produce links which will develop the largest and most uniform percentages. Our records again supply the required data. We find the irons A, B, O, and F, which were *low* in tensile strength, sustained the process of manufacture into links with less loss of strength than did other irons which exceeded in this respect, and with all of the series excess of tensile strength was accompanied by deficiency in strength and uniformity as cables.

Order of precedence of fourteen irons in tensile strength and resistance to impact as bars, and in welding value as measured by strength and uniformity as links.

	1.	2.	3.	4.	5.	6.	7,	8.	9.	10.	11.	12.	13.	14.
Tensile strength.....	L	K	D2	C2	M	P	N	Fx 1 Px	......	Fx 3	B	A	F	O
Resistance to impact.	A	Fx 3	Fx 1	F O	....	D2	P C2	......	Px B	......	M	K	N	L
Welding value.......	A B	......	O	Px	F	D2	Fx 3	C	N	P	Fx 1	....	K	L M

The great tensile strength of L (66,000 pounds), and of K (58,226 pounds), while giving them the highest numbers as bars under tension alone, did not prevent their taking very low rank when tested as cable and by sudden strains. While with irons A and O, with average tensile strength of 52,000 pounds, the result is reversed, the percentage of the bar's strength developed by the links of the four irons were of L 150 per cent. irregular; of K, 151 per cent. irregular; of A, 168 per cent., and O, 166 per cent., both regular.

We have, therefore, guided by the evidence of which the above is a type, decided upon adopting a low *tensile strength* as a probable indication of *high welding* value, and as shown by the relative order as judged by the power of resisting sudden strains, of great resilience.

In selecting the low tensile strength, we did not decide arbitrarily in favor of the precedence which should be given to the percentage of bars' strength developed by links. We find that in many cases the actual strength of the links made from the *bars* of low tensile strength equals and exceeds that of others from much stronger bars.

For example, iron K 2″ bar, tensile strength 58,900 pounds; strength of links, 258,900 pounds.

Iron A, tensile strength 2″ bar, 50,171 pounds; strength of link, 265,000 pounds.

Iron D, tensile strength 2″ bar, 51,152 pounds; strength of link, 276,500 pounds.

Iron F, tensile strength 2″ bar, 48,956 pounds; strength of link, 268,750 pounds.

And our records supply many more instances where the strength of links made from iron of low tenacity exceeds that of others of the same size made from stronger bars, and in nearly all cases the percentages of the bars' strength are greater and more uniform. We have, therefore, decided upon recommending for cable manufacture iron of this character, aware that in so doing we will come in contact with a widely spread and deeply rooted prejudice in favor of the *strong bar* as best adapted to make *strong links*, as it undoubtedly would be were it not that great strength in the direction of the fiber is not often found to exist except through the effect of a great amount of work, which will cause the iron to be too expensive for cable iron, or through the presence of various chemicals which increase tenacity at the expense of welding properties, thus unfitting it for use as cable iron.

We consider that our experiments justify us in recommending as a suitable strength for a 2″ bar of chain iron a mean between the margins found to exist in those bars whose record both in bar and link form has been just given; and as the links of iron D, with tensile strength 51,152 pounds, and of iron F, with 48,956 pounds, were equally good and strong, we adopt their mean of 50,000 pounds. And we find that iron A, which possesses nearly the medium strength as a bar (50,171 pounds), produces cable which is remarkably strong and uniform.

Considering, then, that an iron is suitable which, as a 2″ bar, has a strength of 50,000 pounds per square inch, and that other irons whose variations from this strength does not exceed 5 per cent. are equally so, we have, in determining the strength for the other sizes, to avail ourselves of the information procured in the investigation of the action of the rolls; which is, in brief, that the proportional strength of bars of the same material increases as the diameter decreases, and that the aggregate of the increase for the sixteen sizes (measuring by sixteenths of an inch, between 2″ and 1″) is from 4,000 to 6,000 pounds, produced by steps which are made more or less irregular by irregularities in heating the piles.

Using the mean of the aggregate of increase of our best and most uniform irons, we find that the strength per square inch of a bar of 1″ diameter is about 5,600 pounds greater than that of the 2″, and that if the 2″ bar is equal to 50,000 pounds, it is probable the 1″ will be equal to 55,600 pounds.

Examining this factor by comparison with actual results, as in the case of the 2″, we find that it may be considered as a very suitable strength, subject to the variation of 5 per cent., as in the first case, which gives from 53,000 to 58,000 pounds as a suitable strength for the 1″ bar. From our records, we find that the 1″ bar of iron A, with tensile strength 54,690 pounds, produced cable equal to 69,600, 71,700, and 72,700 pounds; iron F, tensile strength 51,900 pounds, cable equal to 67,600 pounds; while iron P, with tensile strength of 58,000 pounds, as cable broke at 60,400 pounds. We tested but comparatively few links of 1″, but the comparison of the 1⅛″, of which we tested a number, shows the failure of an excess of tensile strength to benefit the links. Iron A, with tensile strength 53,700 pounds, making links equal to 89,000 pounds; iron F, with tensile strength of 53,000 pounds, as links broke at 86,000 pounds; while K, with 60,500 pounds, and D, with 59,500, broke at 84,500 and 87,500 pounds.

It was necessary to connect these strengths assigned to the extremes by a series of successively increasing factors, the aggregate of which should equal 5,600 pounds. No system by which this could be done with certainty presented itself, but it was evident that a *uniform* coefficient of increase for each of the sixteen reductions could not be used, as the difference in strength produced by variations in reductions, changed much less rapidly than did that in the entire strength of the various-sized bars produced by variations in diameter. We considered that this difference was greater in proportion to the entire strength, as the latter became less through decrease of area, and we therefore calculated a ratio which produced a constantly increasing coefficient to be applied as the diameters decreased, with results as follows, each of which results is the correction to be added to the strength per square inch of any size in order to obtain that of the size $\frac{1}{16}$″ less in diameter. Starting with 50,000 pounds as the strength of the 2″, we add 245, 253, 262, 273, 284, 296, 309, 323, 339, 357, 376, 398, 423, 451, 484, and 523 pounds for each reduction of $\frac{1}{16}$ of an inch in diameter, by which we arrive at a strength per square inch for each size which agrees closely with that found in the best and most uniform chain-irons. The latter, however, being exposed to constant chances of irregularities from many causes, cannot be expected to coincide in strength very closely with any calculated table.

Using the above factors of correction, we obtain the following table:

Probable strength of round bars, calculated with an allowance for variation in strength due to variation in diameter.

Size of bar.	Strength of bar.		
	Per square inch.	Coefficient of increase.	Of entire bar.
Inches.	*Pounds.*	*Pounds.*	*Pounds.*
2	50, 000	245	157, 080
1 15/16	245	253	148, 137
1 7/8	498	262	139, 430
1 13/16	760	273	130, 966
1 3/4	51, 033	284	122, 745
1 11/16	317	296	114, 770
1 5/8	613	309	107, 040
1 9/16	922	323	99, 560
1 1/2	52, 245	339	92, 322
1 7/16	584	357	85, 339
1 3/8	941	376	78, 607
1 5/16	53, 317	398	72, 133
1 1/4	715	423	65, 914
1 3/16	54, 138	451	59, 958
1 1/8	589	484	54, 261
1 1/16	55, 073	523	48, 800
1	596	....	43, 665

Accepting this rate of increase of strength as one which *approximates* to the actual increase of tenacity of iron bars of decreasing diameter, we have used it in the calculation of our proof-table. As this is the basis upon which the table is constructed, the following evidence is submitted, by which it may be seen that by the use of the corrections a more correct estimate can be made of the strength of a bar of any diameter than by the assumption that the tensile strength of all diameters is equal. The comparison of the strength, as found, of a large number of bars of various irons and sizes with that calculated proves that our corrections are not far out. (See table, page 94.)

A few examples will be given, which show conclusively that by means of the corrections for variation in diameter given in the table the strength of a bar of, say, 2″, can be closely estimated from the data furnished by the test of a 1″ bar. Selecting irons A, F, O, and P, which were quite uniform, the strength of the 2″ bars was:

Actual strength	A 157,630 lbs.,	F 150,413 lbs.,	O 151,597 lbs.,	P 159,720 lbs.
Calculated with correction	A 154,100 lbs.,	F 151,346 lbs.,	O 148,989 lbs.,	P 163,800 lbs.
Calculated without correction	A 181,836 lbs.,	F 163,136 lbs.,	O 166,635 lbs.,	P 181,600 lbs.

The latter process involving an *overestimate* of from 12,700 to 24,200 pounds, which error is reduced in two cases by the use of the corrections to an overestimate of 4,080 and 933 pounds, and in others to an underestimate of 3,448 and 2,608 pounds. Had the strength of the *links* of the 2″ been calculated from the erroneous strength of the bar, the error would have proved much more serious, as, for instance, with iron A, using 170 per cent., 163 per cent., and 155 per cent. of the strength of the bar for the maximum, average, and minimum strength of links, the strength* compared with that actually found would be as follows: Calculated maximum, 311,121 pounds; average, 296,346 pounds; minimum, 281,850 pounds. By test, the actual strength was, maximum, 283,200 pounds; average, 264,000 pounds; minimum, 244,000 pounds.

The following table has been prepared, in which the average strength of such bars as have produced good cables is placed in contrast with the strength called for by the calculated table:

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*The factors of increase representing the variation due to variation in area, plus correction for variation of effect of rolls.

Comparison of calculated with actual strength of bars.

Size of bar.	Strength.		Difference.	Irons represented in averages.		
	Calculated.	By actual tests.		Number of irons.	Number of tests.	Name of irons.
Inches.	*Pounds.*	*Pounds.*	*Pounds.*			
2	157, 080	157, 580	500	9	35	A, C, D, E, F, Fx, M, O, P.
$1\frac{15}{16}$	148, 137	....	....	.....	.....	
$1\frac{7}{8}$	139, 430	141, 120	1, 690	9	26	Same as 2″.
$1\frac{13}{16}$	130, 966	131, 975	1, 009	5	8	B, C, E, G, H.
$1\frac{3}{4}$	122, 745	124, 580	1, 835	13	83	A, C, D, E, Fx, G, H, J, F, O, N, P, M
$1\frac{11}{16}$	114, 770	115, 690	920	4	7	B, C, G, E.
$1\frac{5}{8}$	107, 040	108, 800	1, 760	10	25	A, C, D, E, F, Fx, G, H, J, O.
$1\frac{9}{16}$	99, 560	....	....	.....	.....	
$1\frac{1}{2}$	92, 322	93, 358	1, 036	13	34	Same as $1\frac{3}{4}$″.
$1\frac{7}{16}$	85, 339	85, 000	339	6	12	B, C, E, G, H, P.
$1\frac{3}{8}$	78, 607	79, 311	704	9	27	A, C, D, E, F, Fx, N, O, P.
$1\frac{5}{16}$	72, 133	74, 505	2, 372	1	94	P.
$1\frac{1}{4}$	65, 914	66, 724	810	9	106	Same as $1\frac{3}{8}$″.
$1\frac{3}{16}$	59, 958	....	....	.....	...	
$1\frac{1}{8}$	54, 261	54, 570	309	9	20	Same as $1\frac{3}{8}$″.
$1\frac{1}{16}$	48, 800	....	....	.....	.....	
1	43, 665	44, 126	461	6	26	A, D, F, Fx, O, P.

Having thus fixed upon a suitable strength for each-sized bar, we deduce the probable strength of cables made from them by the aid of the percentages of the bar's strength which we have found will probably be developed by the links as indicated by those found in such irons as we have examined.

In this table of strength of links it is considered that no iron should be expected to possess in link form over 170 per cent. of the bar's strength, and that no suitable chain-iron should possess less than 155 per cent. of the same; and that the average strength of a number of tested sections should not be less than 163 per cent., such average to be made from fairly uniform factors.

Probable strength of cables, made from bars with strength corresponding to that given in table.

Size of bar.	Strength of—			
	Bars.	Chain links.		
	Strength of entire bar.	Maximum, 170 per cent. of bar	Average, 163 per cent. of bar.	Minimum, 155 per cent. of bar.
Inches.	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*
2	157, 080	267, 036	256, 040	243, 474
$1\frac{15}{16}$	148, 137	251, 833	241, 463	229, 612
$1\frac{7}{8}$	139, 430	237, 031	227, 271	216, 116
$1\frac{13}{16}$	130, 966	222, 642	213, 475	202, 997
$1\frac{3}{4}$	122, 745	208, 666	200, 074	190, 255
$1\frac{11}{16}$	114, 770	195, 109	187, 075	177, 894
$1\frac{5}{8}$	107, 040	181, 968	174, 475	165, 912
$1\frac{9}{16}$	99, 560	169, 250	162, 283	154, 318
$1\frac{1}{2}$	92, 322	156, 947	150, 485	143, 099
$1\frac{7}{16}$	85, 339	145, 076	139, 103	132, 275
$1\frac{3}{8}$	78, 607	133, 632	128, 129	121, 842
$1\frac{5}{16}$	72, 133	122, 626	117, 577	111, 806
$1\frac{1}{4}$	65, 914	112, 054	107, 440	102, 167
$1\frac{3}{16}$	59, 958	101, 929	97, 731	92, 935
$1\frac{1}{8}$	54, 261	92, 244	88, 445	84, 105
$1\frac{1}{16}$	48, 800	82, 960	79, 544	75, 640
1	43, 665	74, 230	71, 172	67, 681

It is very probable that in every finished cable there will be some links introduced the strength of which, although not *less* than the minimum of the table, will be considerably below the maximum, and furnish the lower factors from which the averages are produced; and it is also probable that, through defective welds, there may be a few links whose strength is even less than the minimum. A proof-strain should not be so great that its application will have a tendency to reduce the strength of the first-named class to that of the second, nor should it be so slight that links of the second class will be so slightly affected that their existence is not made manifest.

We cannot adopt a safer strain than one which approximates to the *elastic limit* of the link, and the link whose elastic limit we should adopt is the *weakest* one which will, after proof, remain in the cable.

We have endeavored to ascertain by actual experiment the elastic limit of many of the links that we have broken. We have found that, as with the strength of the link, this factor can at the best be but approximated, but consider that the proportions found to exist between the limit of elasticity and the strength of the round bars from which the links are made furnish us with a maximum beyond which we cannot expect that of the link to be found. We have found, by a great number of tests of bars in their normal condition, that the elastic limit of good cable iron is about 57 per cent. of its ultimate strength. (See record of bar-tests.)

The process by which the links are manufactured undoubtedly changes both the strength and elastic limit of the portion upon which the welds are made; the extent of this change we have no means of knowing, and so irregular are the processes of manufacture that, if accurately ascertained in regard to a tested link, the data would be of no value in estimating its extent in the case of another.

We are therefore again reduced to probabilities. Generally, the elastic limit of material is coincident with the first perceptible permanent change of form produced by stress. With a chain-link this cannot be accepted as correct, as through various causes the *form* of the link may change at a stress not great enough to produce change in the atomic relations of the material. Still, this first change of form *indicates* an approach to this limit, and we have carefully observed it in the test of many links, and find that with such irons as A, B, C, F, P*x*, and others considered suitable for cable, the percentage of the stress which will break the cable, at which the elongation can be observed and measured, is about 44 per cent., and that this percentage exists with considerable regularity, so much so that we feel justified in assuming it as the nearest approximation to the elastic limit of the link that can be deduced from our experiments. But we believe, for several reasons, that in most cases it is too low a percentage; first of which is, that through badly fitting studs, many links, during the beginning of an increasing stress, may be considered as open or unstudded ones, and the "first stretch" is produced by a slight closure of the sides upon the stud; and open links begin to stretch at a much lower stress than studded ones. It is probable that a mean between the ratios of the ultimate strength at which the material in bar form begins to stretch, viz, 57 per cent., and that at which the links first elongate, viz, 44 per cent., will give as nearly the probable elastic limit of the link as can be obtained by any other process. No exact limit can be fixed upon.

An iron with low tenacity and high elastic limit will naturally, when subjected to stress, act very differently from one in which these elements are reversed in value. An iron whose characteristics are such that the process of welding lowers the ultimate strength of the welded part, may still be able to resist, through its stiff and brittle nature, a very high stress before it begins to change form, but it may break at a slight additional stress. We have in calculating the proof-strains assumed that it is not safe to use above 50 per cent. of the strength of the weakest part of the cable.

There is still another reason, deduced from our experiments, which leads us to recommend a lower proving-strain. In our investigation of the law of the elevation of the limit of stress, we have found that although wrought iron acquires increased power to resist *steady* stress by the action of stress previously withstood, yet its power to resist *sudden* stress is lowered, and for this reason the operation of the law is injurious to cables.

The proving-strains, calculated upon the principles indicated, are as follows, and they have been adopted as the—

UNITED STATES STANDARD PROOF-TABLE FOR CHAIN CABLES.

[Strains being equal to 45.57 per cent. of the strength of the strongest and to 50 per cent. of that of the weakest links.]

Size.	Proving strain.		Minimum breaking strain.	
	Pounds.	Tons.	Pounds.	Tons.
″ 1	33,840	15.10	67,680	30.20
1 1/16	37,820	16.90	75,640	33.80
1 1/8	42,050	18.80	84,100	37.60
1 3/16	46,470	20.75	92,940	41.50
1 1/4	51,080	22.75	102,160	45.50
1 5/16	55,900	24.95	111,800	49.90
1 3/8	60,920	27.20	121,840	54.40
1 7/16	66,140	29.50	132,280	59.00
1 1/2	71,550	31.95	143,100	63.90
1 9/16	77,160	34.50	154,320	69.00
1 5/8	82,960	37.00	165,920	74.00
1 11/16	88,950	39.70	177,900	79.40
1 3/4	95,130	42.45	190,260	84.90
1 13/16	101,500	45.30	203,000	90.60
1 7/8	108,060	48.25	216,120	96.50
1 15/16	114,800	51.25	229,600	102.50
2	121,740	54.35	243,480	108.70
2 1/16	128,920	57.60	257,840	115.20
2 1/8	136,290	60.80	272,580	121.60
2 3/16	143,870	64.25	287,740	128.50
2 1/4	151,640	68.00	303,280	136.00

This proof-table differs from all others at present in use, among which are those of the British, French, and United States Governments, in many important points, among which the following may be noticed:

First. The strains recommended are based upon the actual strength found in a fair average lot of American irons, tested with care by all known methods, and the results carefully studied and compared.

Second. In calculating these strains, the error which has prevailed, that the strongest links are made from the strongest bars, has been eliminated, and allowance made for the low tensile strength which it is absolutely necessary to have in good chain iron, to insure good welding qualities and freedom from brittleness.

Third. In this table, allowance is made for the variation in proportional strength accompanying variations in diameter of bar, and thus all sizes are strained to the same proportion of their strength, the strains prescribed *decreasing regularly* as the diameters increase, from 43,000 pounds per square inch upon the 1″ to 38,000 on the $2\frac{1}{4}''$. In the British Admiralty standard the strain upon all sizes is *uniform* at 51,300 pounds per square inch. In the United States Navy proof-table, for which that of the Board has been substituted, the strains *increase irregularly* with each increase of diameter, from 34,000 pounds per square inch upon the 1″, to 37,200 pounds upon the $2\frac{1}{4}''$.

Fourth. In this table, due weight has been given to the fact discovered by two members of the Board, that strain carried beyond the elastic limit causes the iron strained to become brittle and, although possessing more power to resist steady strains, to lose power to resist sudden strains, and the elastic limit of the links has therefore been sought for, found, and utilized.

Fifth. In this table the possibility is recognized of there being introduced into cables, links made from bars which, although of the same iron, are, through faults in rolling, more or less *scant*, and thus possess less strength than bars rolled true, which deficiency will be carried into the links. Should there by accident be a few links of $1\frac{15}{16}''$ in a 2″ cable, the Admiralty proof would strain the strongest of such links to over 62 per cent. and the weakest to over 70 per cent. of the actual strength.

For these reasons we recommend that this table, based upon actual strength of American iron, be used in testing American chain, in place of that of the British Admiralty, which is based upon a standard tensile strength of 60,000 pounds per square inch, a strength which American chain-iron does not possess.

This proof-table having been submitted by the editor, to the Navy Department, has, as shown by the following letter, received its official indorsement, and has become the United States standard:

NAVY DEPARTMENT,
BUREAU OF EQUIPMENT AND RECRUITING,
Washington, D. C., October 19, 1881.

SIR: The proof table for testing chain cables, submitted in your letter of this date, has been examined and is hereby approved, and will be adopted as the standard of the Navy of the United States.

Very respectfully,

EARL ENGLISH,
Chief of Bureau.

Capt. L. A. BEARDSLEE,
United States Navy.

A portion of the examination of this table consisted in a comparison of its figures, which show what strength good chain cable should have, with the results of experiments carried on by a board of officers under the Bureau of Equipment, for the purpose of determining the comparative strength of various sized wire and hemp ropes, chain cables, &c., during which the following remarkable coincidences were observed:

Strength of various-sized chain cable as found by actual tests by Equipment Board and as calculated by United States Iron Board.

Diameter.	Strength found by Equipment Board.*	Strength calculated by United States Iron Board.
"	*Pounds.*	*Pounds.*
1	63, 360	67, 700
1 1/8	78, 220	84, 100
1 3/16 full	94. 650	92, 940
1 1/4	103, 430	102, 100
1 5/16	112, 640	111, 800
1 3/8	122, 220	121, 840
1 7/16	182, 200	132, 280
1 7/16 full	142, 560	
1 1/2	....	143, 100

Throughout the sizes other coincidences exist.

Comparison of the proving-strains of various proof-tables.

Size of cable.	United States proof-table, calculated in 1830.	Recommended proving-strains.	Probable percentage of strength of—		French and British Admiralty proving-strains.	Probable percentage of strength of—	
			Strongest link.	Weakest link.		Strongest link.	Weakest link.
Inches.	*Pounds.*	*Pounds.*			*Pounds.*		
2	117, 600	121, 737	45. 5	50	161, 280	60. 3	66. 2
1 15/16	108, 600	114, 806	45. 5	50	151, 357	60. 1	65. 9
1 7/8	100, 800	108, 058	45. 5	50	141, 750	59. 8	65. 5
1 13/16	91, 800	101, 499	45. 5	50	132, 457	59. 4	65. 2
1 3/4	87, 800	95, 128	45. 5	50	123, 480	50. 1	64. 9
1 11/16	83, 200	88, 947	45. 5	50	114, 817	58. 8	64. 5
1 5/8	78, 000	82, 956	45. 5	50	106. 479	58. 5	64. 1
1 9/16	72, 000	77, 150	45. 5	50	98, 437	58. 2	63. 7
1 1/2	66, 200	71, 550	45. 5	50	90, 720	57. 8	63. 3
1 7/16	61, 200	66, 138	45. 5	50	83, 817	57. 4	62. 9
1 3/8	56, 000	60, 920	45. 5	50	76. 230	57. 0	62. 5
1 5/16	50, 400	55, 903	45. 5	50	69, 457	56. 6	62. 1
1 1/4	44. 800	51, 084	45. 5	50	63, 000	56. 2	61. 6
1 3/16	40, 000	46, 468	45. 5	50	56, 857	55. 7	61. 1
1 1/8	34, 600	42, 053	45. 5	50	51, 030	55. 3	60. 6
1 1/16	30, 600	37, 820	45. 5	50	45. 517	54. 8	60. 1
1	26, 800	33, 840	45. 5	50	40, 320	54. 3	59. 5

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*Extracts from "Report of Board for testing plain and galvanized iron and steel wi0e, &c., &c.," conducted at Navy-yard, Washington, D. C., 1878 and 1879.

[APPENDIX.]

SECTION III.

NOTES UPON THE IRONS EXAMINED.

PART. 1. NOTES UPON THE VARIOUS IRONS EXAMINED, WITH EXPERIMENTS SHOWING EFFECTS PRODUCED BY REWORKING MATERIALS OF DIFFERENT CHARACTERISTICS.—PART 2. CHEMICAL ANALYSIS OF THE IRONS, WITH COMPARISON OF THE CHEMICAL AND PHYSICAL RESULTS.

PART I.

A comparison of the results obtained by steady and sudden strains upon bars, and by steady strains upon the links made from the bars, indicates that there are two classes of iron, which, although possessing considerable tensile strength in the form of straight bars, are equally unsuitable for cable-iron, through defective resilience, or inferior welding qualities.

The first class includes the greater portion of the ordinary cheap iron found in the market, which iron is cheap because it has not received enough work, which is expensive, to greatly change its characteristics from those which it possessed as crude iron.

When tested by tension, iron of this class shows slight change of form at rupture, and when broken by impact it proves brittle and unreliable under sudden strains.

After fracture the appearance of the broken surface is described as "coarse granulous," and generally is bright and glistening.

Such iron will, when subjected to impact, break with but little deflection, and sometimes by blows of less force than it had previously withstood without sign of injury.

The second class includes many excellent irons with high tenacity, which is due either to very thorough work, or to ingredients in its composition which tend to increase tenacity, frequently at the expense of welding qualities.

A few notes in regard to the irons we have examined will illustrate these points.

CONTRACT CHAIN-IRON.

Record of bars tested by tension, Nos. 1 to 65; by impact, Nos. 1 to 85; chemical analysis, No. 156.

The tests upon this iron were made by the chairman of the committee, in obedience to an order of the Navy Department.

The general character of the iron was that of class first, coarse, brittle, and slightly worked.

As a result of the tests the entire stock on hand was condemned, but much of it having been found to be susceptible of great improvement by reworking, it was so treated with good results.

Using this iron as a basis for experiments in reworking and in mixing irons with differing characteristics, we produced the

HAMMERED IRON.

Record of bars tested by tension, Nos. 66 to 111, inclusive; by impact, Nos. 86 to 304.

The process by which this iron was manufactured was as follows:

Such of the contract chain-iron as our experiments had shown to be most benefited by increased work was selected, heated to a very high heat, and thoroughly hammered by the steam-hammer, each link or bolt

PLATE VI.

IMPACT TESTS.

Fig. 1.

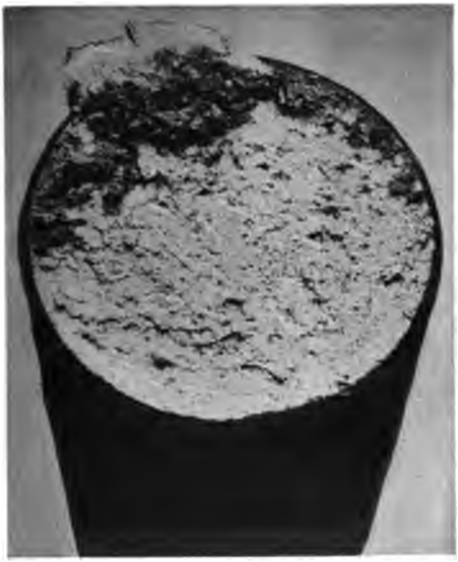
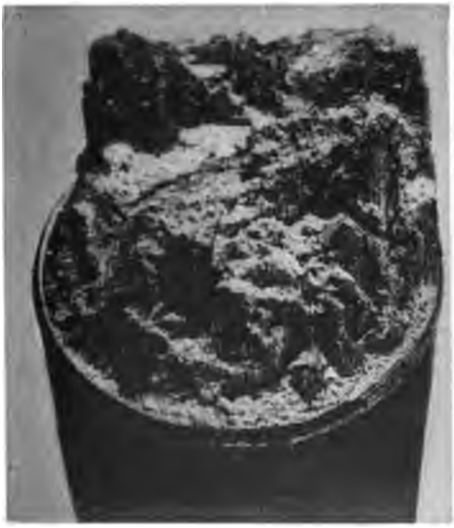


Fig. 2.



Heliotype Printing Co., 211 Tremont Street, Boston.

CONTRAST IN THE APPEARANCE OF FRACTURES BY IMPACT MADE UPON EXTREMELY BRITTLE AND EXTREMELY TOUGH IRONS.

Fig. 1. Contract Chain iron 2 3-16 in. bar.
" 2. Hammered iron from the 2 3-16 in. bar, combined with old boiler iron.

by itself, until it was flattened to a slab. During the process great quantities of dross and scoria were expelled.

Old condemned boilers were cut up, and the better portions cut into slabs, which were heated to a red heat and the rust beaten off; these slabs of the two irons were then piled in the following manner:

Boiler-iron.
Twice-hammered chain-iron.
Once-hammered chain-iron.
Crown-sheet boiler-iron.
Once-hammered chain-iron.
Twice-hammered chain-iron.
Boiler-iron.

These piles were about 20″ by 10″, and were heated and hammered into octagonal blooms.

The advantages which it was hoped would be secured by the above method of piling were, that the soft and comparatively plastic center would permit extreme flexure; that the coarse once-heated chain-iron would, being supported by this yielding center, sustain flexure to a much greater extent than if not so supported; and that the thoroughly reheated and reworked layers of chain-iron next to the outer layers would impart strength and toughness to the mass, and would absorb any blows or sudden strains, which received upon the outer surface would encounter first a cushion, and then a tough iron; and that the resultant iron would possess great power to resist both sudden and steady strains, would bend double without breaking, and the parts not being perfectly homogeneous, the rupture of a portion of a bar would not render valueless the remainder. That we secured all these advantages our tests show plainly.

Tested by tension, the iron showed fair tensile strength (average 53,000 pounds), uniformity, and ductility; tested by impact, bars of all sizes, in their normal condition, would sustain heavy blows with slight deflection, and finally double till the sides were close together, without injury. Extreme tests were made by impact; one hundred and ninety-seven bars of 2″ diameter were swaged from the blooms, each of which was circled with a score $\frac{1}{32}''$ deep in the center; these bars were struck upon this score by the wedge-shaped hammer of the impact testing-machine, dropped from a height of 30 feet, the hammer weighing 100 pounds. Each blow was considered to be equal to 3,000 foot-pounds.

2, or 1 per cent., resisted 7 blows.
5, or 2.54 per cent., resisted 6 blows.
27, or 13.6 per cent., resisted 5 blows.
68, or 34.5 per cent., resisted 4 blows.
71, or 36 per cent., resisted 3 blows.
21, or 10 per cent., resisted 2 blows.
3 broke at first blow.

The three which broke at a single blow were found to have been made partially of boiler-steel.

IRON A.

From these hammered blooms, those which had resisted at least three blows were reheated and rolled in the copper-mill into the above iron, of which the—

Record of tests by tension as bars is Nos. 112 to 162; by impact as bars, Nos. 305 to 467; of links, Nos. 1 to 41; chemical analysis, 135.

The greater portion of iron A was rolled into 2″ bars, the fag-ends being reduced still further to 1¼″, and a portion of one day's work was rolled into bars of all sizes from 1″ to 2¼″, varying by eighths of an inch.

The tests by tension of the 2″ bars showed tenacity quite uniform, averaging about 50,000 pounds, that of the bars varying in diameter ranging from 51,000 to 55,000 pounds.

The blooms for the sizes from 2″ to 1⅝″, inclusive, were of uniform area, as were those of 1½″ to 1″, inclusive.

All of the bars showed great ductility and change of form under tension, having a rather low elastic limit, which was due, no doubt, to the fact that the softer and more ductile portions stretched first. Tested by impact all sizes up to 2¼″ bent completely double by heavy blows (3,000 foot-pounds) delivered upon the center of the test pieces, bending them to the face of the wedge, when the steam-hammer completed the closure, as shown, (Plate VII.)

Sixty of the bars of the 2″ rolled were tested by impact in the same manner as the hammered iron.

1, or 1.66 per cent., resisted 7 blows.
1, or 1.66 per cent., resisted 6 blows.
8, or 13.33 per cent., resisted 5 blows.
14, or 23.33 per cent., resisted 4 blows.
16, or 26.66 per cent., resisted 3 blows.
14, or 23.33 per cent., resisted 2 blows.
6 broke at less than 2 blows.

Fractures showing long gray fiber and "barking," as shown, (Plate IV.)

Eighty-three tests by impact were made upon the 1¼″ bars, all being scored with a circle $\frac{1}{32}$″ deep and struck by the 100-pound hammer dropped 30 feet, the temperature being from 20° to 35° during test, and the bars having been exposed the preceding night to a temperature of 10° to 15°.

Sixty-one pieces withstood this blow without breaking, many being hardly cracked. Most of those which broke showed fibrous structure.

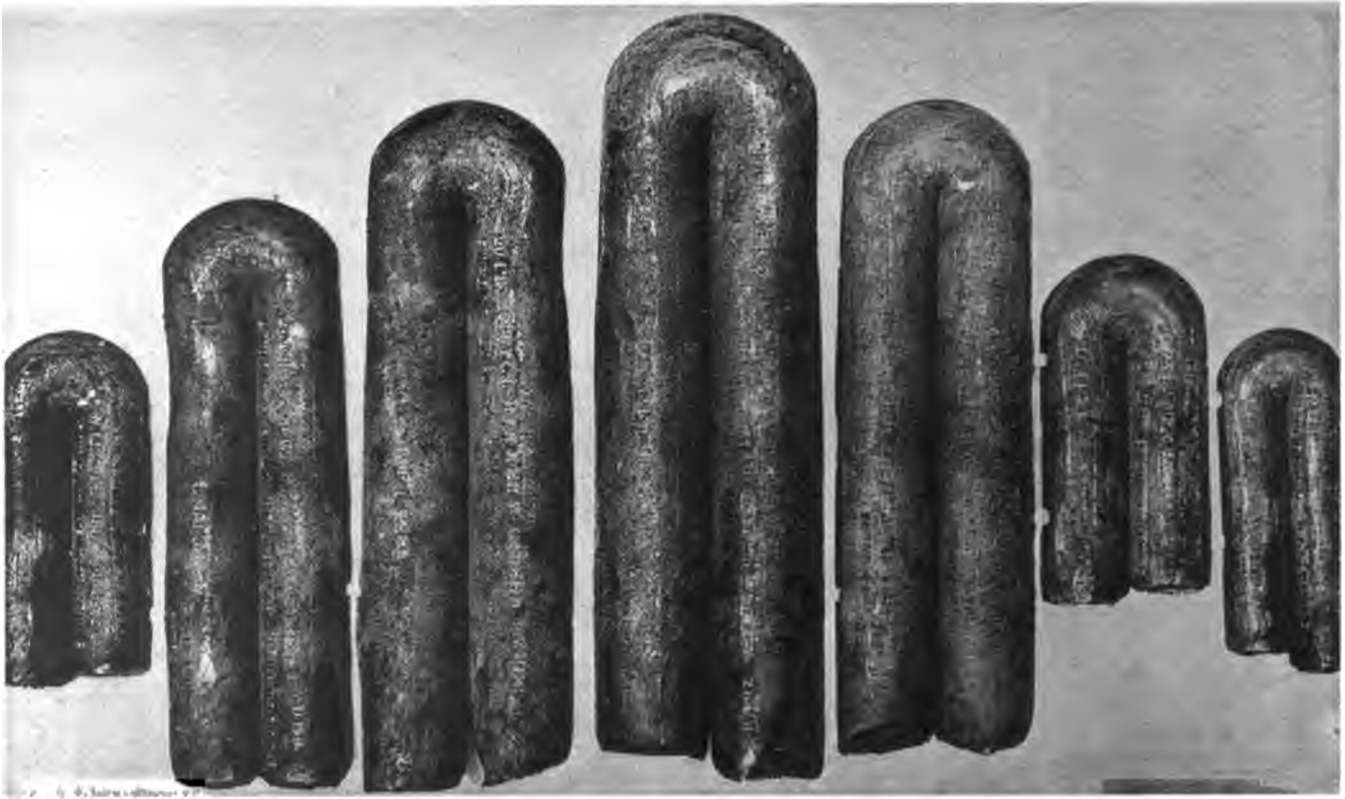
It is probable that the final heating and rolling deprived the iron of a portion of its power to resist shocks, as the record of the hammered iron is superior to that of the rolled in this respect. Tested as cable, the links of all sizes proved strong, and the welding value of the iron was good, a large proportion of the links (18 out of 37) breaking at the butt end. The strength of links ranged from 161 per cent. to 173 per cent., averaging 169 per cent. of the bar's strength.

No iron which we have examined has proved superior to this for cable-iron, and there is no reason why any manufacturer should not be able to produce similar material by suitable mixtures in the piles, and by giving such amount of work as is found to be best adapted to develop good welding properties.

Even though it should be considered as impractical to arrange every pile with due attention to a balancing of opposite characteristics, the quality of ordinary chain-iron can be vastly improved by subjecting the coarse material of which it is generally composed to much more thorough working than is ordinarily the custom.

PLATE VII.

IMPACT TESTS.



Heliotype Printing Co. 211 Tremont Street, Boston.

BARS OF IRON A, OF DIAMETER FROM 2 1-4 IN. TO 1 1-8 IN., BENT DOUBLE, COLD, BY HEAVY BLOWS.

PLATE VIII.

IMPACT TESTS.

FIG. 1. 1 1-4 in. bar.

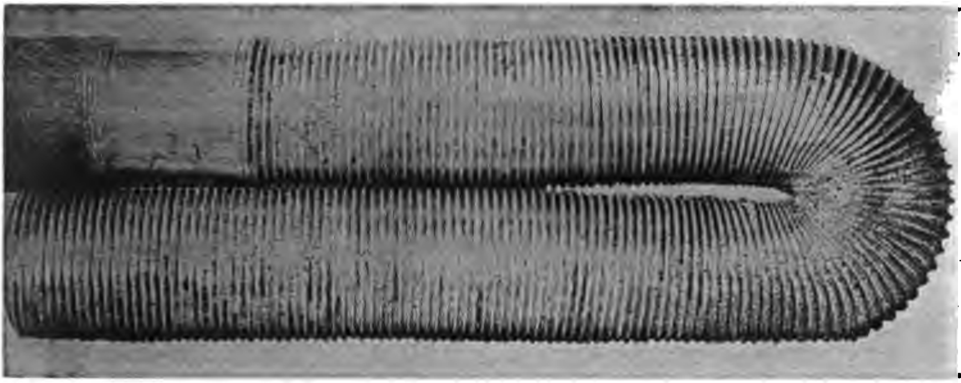


FIG. 3. 2 1-4 in. bar.

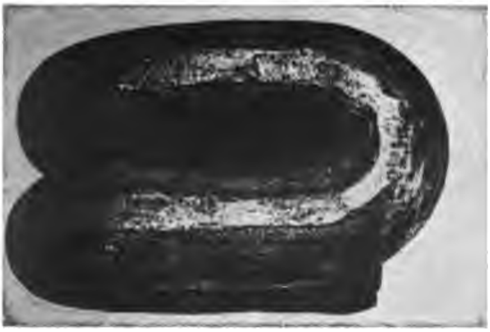
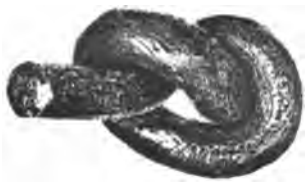


FIG. 2. 1 in. bar.



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HELIOTYPE PRINTING CO. BOSTON.

Iron A.

Figs. 1 and 3 bent cold by heavy blows
Fig. 2 Ends pointed while warm, then cooled and hauled taut.

THE TESTS REPRESENTED BY FIGS. 1 AND 3 ARE TYPICAL, MANY SIMILAR HAVING BEEN MADE UPON THIS IRON.

A number of the test-pieces of iron A which had been tested by impact were photographed, and Plates VII and VIII are heliotypes from these photographs.

Plate VII represents the bars of February 27 as bent by impact.

Plate VIII illustrates a few of the crucial tests to which this iron was subjected.

Figure 1 is a screw, sixteen threads to the inch, which was bent to face of impact hammer by a blow of 3,000 foot-pounds, then closed under steam hammer. Fig. 2, the 1″ bar of February 27, drawn into an overhand knot by tension with machine A. Fig. 3, the $2\frac{1}{4}''$ bar, bent double cold in two directions. Figs. 1 and 3 represent many tests of the same nature, all of which were equally successful.

IRON B.

Record of bars tested by tension, Nos. 163 to 174, and 316 to 352; by impact, Nos. 468 to 478; of links, Nos. 42 to 97; chemical analysis, No. 171.

Three bars of this iron, viz, $1\frac{13}{16}''$, $1\frac{11}{16}''$, and $1\frac{7}{16}''$, were furnished as sample bars to compete for an order for chain-iron, with bars of irons C, E, G, H, I, J, K, and L, all of which are referred to as the "nine irons"; by the result of the tests, this iron was accepted for the three sizes, the contractor having substituted samples of iron B at the last moment for those of iron I, previously furnished, which proved red-short, and worthless. The iron B delivered was about the same as the samples, except in case of the $1\frac{7}{16}''$ size, some of the links of which greatly resembled the rejected iron I. This iron showed plainly the effect upon quality of increased reduction by the rolls, the smaller sizes being the most ductile and welded most firmly. As cable the $1\frac{13}{16}''$ averaged 162 per cent., the $1\frac{11}{16}''$ $166\frac{1}{2}$ per cent., and the $1\frac{7}{16}''$ $176\frac{1}{2}$ per cent. of bar's strength.

IRON C.

Record of tests of bars by tension, Nos. 175, 180, 353 to 409, 450 to 457; by impact, Nos. 479 to 521; of links, Nos. 98 to 156; chemical analysis, No. 172.

Three bars of this iron, viz, of $1\frac{3}{4}''$, $1\frac{5}{8}''$, and $1\frac{1}{2}''$, were furnished to compete with the "nine irons," and upon the results of the tests this iron was received in the above sizes. Bars of $1\frac{13}{16}''$, $1\frac{11}{16}''$, and $1\frac{7}{16}''$ were also furnished, but the price being greater than that of iron B, the latter was selected.

The tests by tension and impact of the *sample* bars Nos. 162, 163, 169, 174, 175, and 181 showed great ductility, low tensile strength, and remarkable toughness, with great power to resist impact, one bar receiving 119 sledge-blows, another 94, and all many, upon ends which had been nicked with a cold-chisel, before they were broken off.

As cable the welding value was high, and the single links developed from 178 per cent. to 199 per cent. of the bar's strength, averaging 187 per cent.

These sample bars in many respects resembled iron D, which is a rivet iron made by the same mill.

The iron delivered differed greatly in characteristics; the tensile strength was higher, they comparing as follows:

	$1\frac{3}{4}$	$1\frac{5}{8}$	$1\frac{1}{2}$
	Pounds.	*Pounds.*	*Pounds.*
Sample bars	50,312	49,000	52,700
Iron delivered	54,400	55,880	55,400

And although generally tough and strong, the characteristics of the iron delivered showed that it had received much less work than the samples, if of the same material. As cable-links, the $1\frac{1}{2}''$ developed an average of 162 per cent., the $1\frac{5}{8}''$ 155 per cent., and the $1\frac{3}{4}''$ 153 per cent. of the bar's strength, made up of very irregular factors, ranging from 134 to 177 per cent. The $1\frac{3}{4}''$ was brittle under impact, the $1\frac{5}{8}''$ less so, and the $1\frac{1}{2}''$ generally very tough.

IRON D.

Record of tests of bars by tension, Nos. 410 to 449, 458 to 463; by impact, Nos. 522 to 548; links, Nos. 157 to 177; chemical analyses Nos. 132, 134, 186, 173, 174.

Two lots of this iron, each consisting of nine bars, from 2″ to 1″, were purchased for testing. It was manufactured by the maker of iron C, and was a "rivet iron." Difference in the amount of reduction in the rolls produced with this iron very marked differences in strength, the smaller bars having much greater tenacity than the larger ones. All sizes possessed great power to resist impact, except the 2″ bars, which were generally very brittle.

The two lots differed greatly in the tensile strength of the same sizes, as shown by comparing: First lot, $1\frac{1}{8}''$, tensile strength, 54,687 pounds; 2″, 51,146 pounds. Second lot, $1\frac{1}{8}''$, tensile strength, 61,115 pounds; 2″, 49,146 pounds, a difference of 11,969 pounds, due apparently to difference in reduction by the rolls.

It seems probable that the second lot, having been prepared expressly for test, received a great deal more work than the first. This overwork manifested itself both in increased tenacity and in decreased welding value, the single links of the first lot developing an average of 178 per cent. and the sections of the second 158 per cent. of the bar's strength.

The 2″ bars of both lots differed greatly from all of the smaller bars, so greatly that it was difficult to believe that they were of the same iron. Both were very brittle under impact, and when tested by tension broke with almost imperceptible change of form, showing bright granulous surface of fracture. With one of these bars there was so slight a difference between the appearances of the fractures by tension and by impact that the fragments were photographed, as shown. (Plate X.) After several failures the manufacturers at last sent us a 2″ bar which corresponded in its character with the smaller sizes.

From this last-named bar the test-pieces used in the investigation of form of test-pieces Nos. 153 to 162 were prepared, by which the tensile strength was found to be about 46,500 pounds, as obtained by a cylinder turned from the core; by test of the entire bar (No. 410, records of bars) it was 51,146 pounds. This remarkable difference between the tenacity of the core and that of the entire bar occurred in another instance, with iron F*x*, a very ductile material too much worked. This 2″ bar of iron D withstood heavy impact tests, and as cable broke at 276,500 pounds, equal to 172 per cent. of the bar's strength.

IRON E.

Record of tests of bars by tension, Nos. 181 to 204, and 476 to 498; by impact, Nos. 549 to 563; of links, Nos. 178 to 202; chemical analysis, 175.

Six bars, viz, $1\frac{13}{16}''$, $1\frac{3}{4}''$, $1\frac{11}{16}''$, $1\frac{5}{8}''$, $\frac{7}{16}''$, $1\frac{1}{2}''$, were furnished to compete with the nine irons, the price being higher than that of B and C; the latter had been tested and bought before E was touched. Upon test, it developing fairly, bars of the intermediate sizes were purchased to complete the series of tests.

PLATE IX.
IMPACT TESTS.

FIG. 1. 1 1-2 in. bar Iron C.

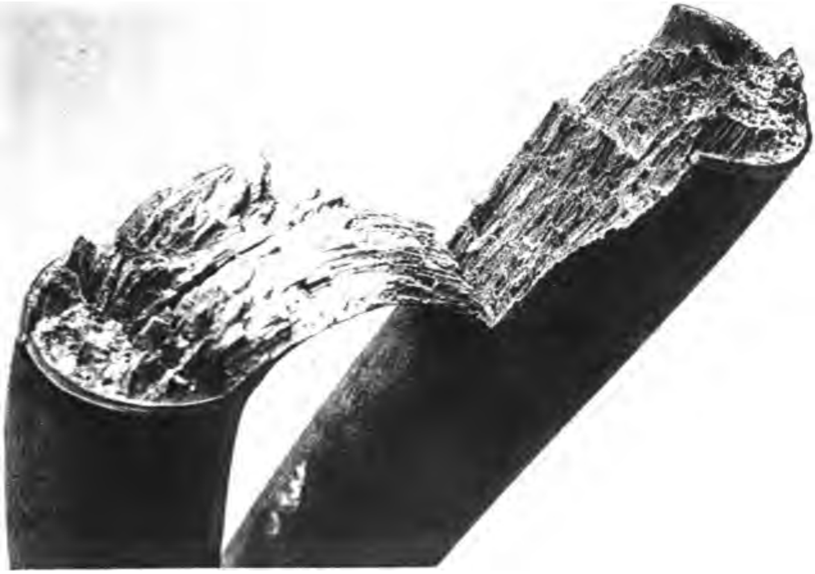
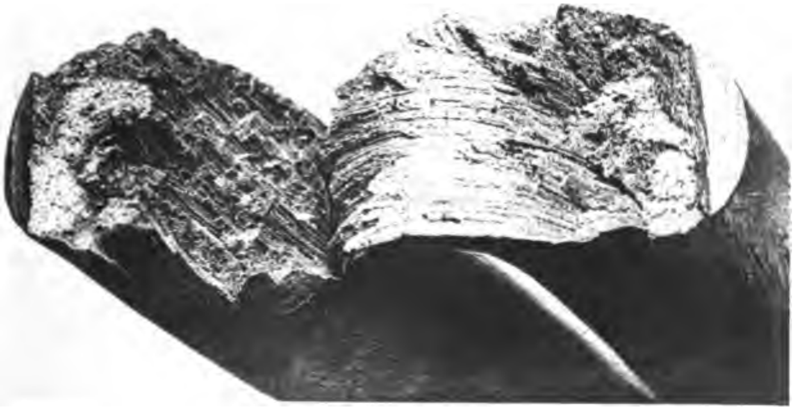


FIG. 2, Iron F.



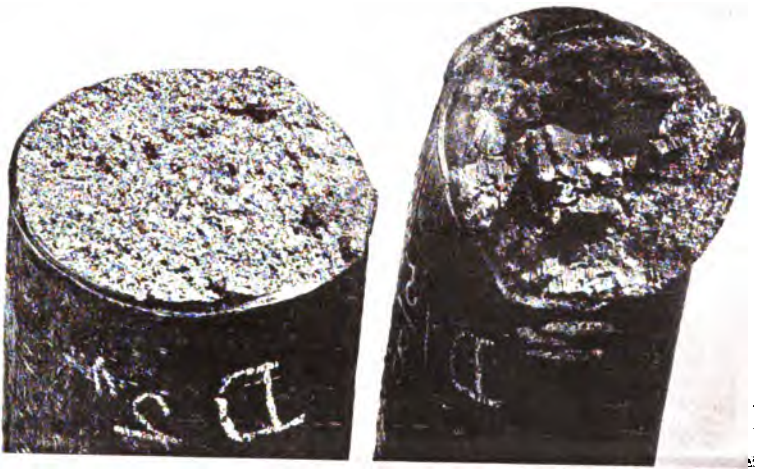
Heliotype Printing Co., 211 Tremont Street, Boston.

FRACTURES PRODUCED BY HEAVY BLOWS.

PLATE X.

Fig. 1.

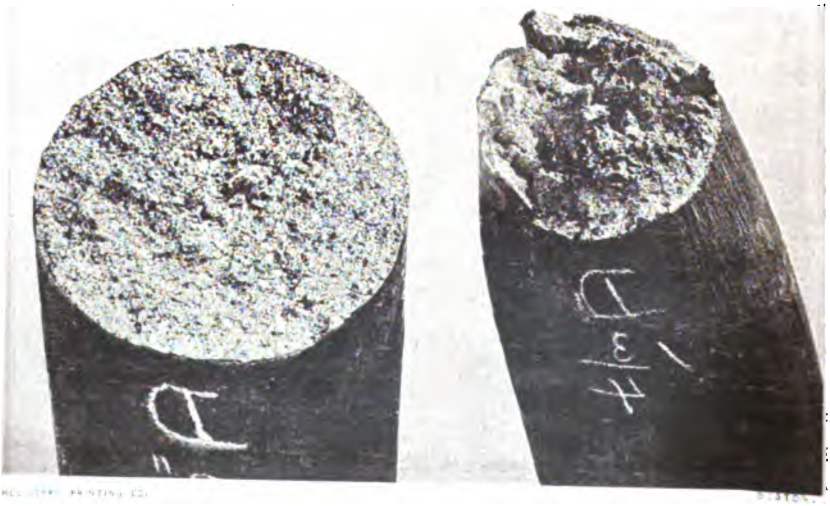
FRACTURES PRODUCED BY IMPACT.



2 in. bar.　　1 5-8 in. bar.

Fig. 2.

FRACTURES PRODUCED BY TENSION.



HELIOTYPE PRINTING CO. BOSTON.

2 in bar.　　1 3-4 in. bar.

SHOWING THE DIFFERENCE BETWEEN THE TWO INCH AND OTHER BARS OF IRON D.

The iron was all of good quality, moderate tensile strength, tough under impact, and made good cable.

This set of bars presented one peculiarity: the 1½″, instead of being of less tensile strength than the 1⅝″, as generally is the case, was of greater, and three other bars, of 1¾″, 1⅝″, and 1½″, were bought to see if this unusual feature was or was not accidental; the same result was repeated, and led to inquiry at the mill for the cause. We found that at this mill the pile used for the 1½″ was of the same sectional area as that for the 1⅝″, while at most mills it is less. (See investigation of effect of rolls, pages 33 and 42.)

IRON F.

Record of tests of bars by tension, Nos. 499 to 752; by impact, Nos. 564 to 572; of links, Nos. 203 to 244; chemical analysis, Nos. 131.

This iron was received in several lots, the first of which proved to be of such uniform character that iron F was selected as suitable to use in various investigations in which it was desirable to reduce to a minimum the chances of error arising from defects in the material.

None of the bars furnished can be considered as chain-iron, for which purpose the manufacturers make a harder and stronger iron. We however, tested many of them in the form of cables, considering that in the record of such cables we would find what could be expected of iron of very low tensile strength. Iron F proved uniform under every form of test, the tensile strength, elongation, reduction of area, strength of links, and percentage of bar's strength developed by links, resistance to impact, and welding qualities of any one lot, furnishing valuable evidence as to what might be expected of another.

The manufacturers furnished us notes as to the process of manufacture of the third lot received, similar to those previously made by the chairman of this committee during the manufacture of the second lot.

The third lot of bars, from ¼″ to 4″, inclusive, was furnished to the Board without charge, and every facility was rendered to us to enable us to study the effect of different amounts of reduction from pile to bar—the results of which experiments are described in the "Investigation of the effect of the rolls," the experimental iron being termed in our report "F*x*".

IRON FX.

Lots 1, 2, *and* 3.

Record of tests by tension of bars, Nos. 753 to 848; by impact, Nos. 573 to 590; of links, Nos. 245 to 262; chemical analyses, Nos. 169, 176, 177.

The bars of this iron were rolled from piles made up of the same combination of crude irons as was used in the manufacture of iron F, but which piles were made to differ from those of F in sectional area.

The proprietors of the rolling-mill furnished without charge all of the facilities and material necessary to assist the committee in an investigation into the effect of the rolls, the object of the experiments being the production of a set of bars of various sizes, the tensile strength per square inch of which should be uniform.

This result was accomplished on the third trial, by so graduating the sectional areas of the various piles that the areas of the bars rolled from them bore uniform ratios to those of the piles. (See investigation of the effect of the rolls, page 44.

The resulting bars had received much more work than iron F; they had higher tenacity, equal if not superior resilience, but *inferior* welding qualities. The average tensile strength of iron F was 51,127 pounds (from 52,517 to 48,132); the average tensile strength of iron F*x* was 53,400 pounds (from 54,644 to 52,817).

The percentage of bar strength developed by links of iron F was, one lot 164 per cent., another 162.5 per cent.; of iron F*x* it was, one lot 151 per cent., another 157.8 per cent.; and the percentages of iron F were more regular than those of F*x*.

Tested by impact, both varieties resisted extreme shocks, and numbere of the test pieces manifested the phenomena of "barking." (See Plats IV.)

IRONS G, H, I, AND J.

Record of bars tested by tension, Nos. 205 to 281; of links, Nos. 263 to 277; chemical analyses of J, Nos. 137, 142, 143, 144, 148.

These bars were furnished to compete with the nine irons for a contract, but few tests were made upon them. G and H both proved of good, fibrous material, sufficiently worked, and the few links made from them were strong; G, as single links, being equal to 174 per cent., and H to 182 per cent. of the bar's strength.

Iron I was thoroughly red-short, and it was impossible to make links from it, they breaking while being bent.

Six bars of iron J were furnished, which proved to be of a kind called in the shop "rotten." When tested by impact with a sledge-hammer, the bars would split under the blows, showing smooth, black faces, resembling charcoal.

IRON K.

Record of tests of bars by tension, Nos. 849 to 895; by impact, Nos. 591 to 618; of links, Nos. 303 to 328; chemical analyses, Nos. 130, 140, and 141.

Several of the bars of this iron were furnished to compete with the "nine irons;" the remainder were purchased at different times for test purposes.

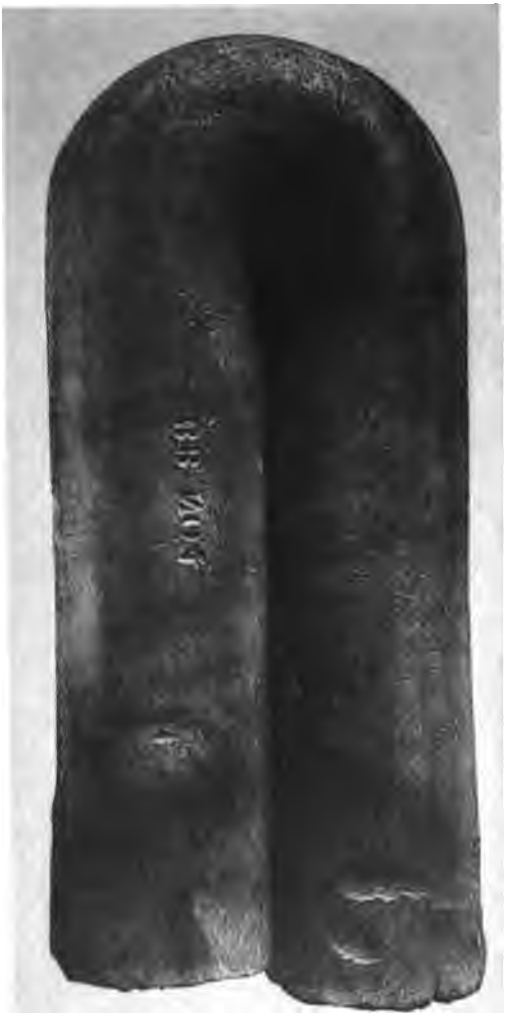
All were of the same character, which was that of a fine-grained, thoroughly worked, refined bar, of great tensile strength and uniformity, showing, when broken by any form of force, fine, bright, silvery fractures.

The bars were so uniform in strength that they were selected as the material from which to make experiments which depended upon uniformity in character of material for their value. Under impact-tests iron K gave peculiar results; if the skin was intact, a bar of 2″ diameter could be doubled cold by heavy blows without showing injury; but if a slight score or nick was made in it this power was entirely lost.

The welding properties were not good; that is, by the ordinary process. With some of the links, that were probably welded at suitable heat; the welds were firm, and they possessed great strength; but others made from the same bars broke at very low strains. By reference to the records on page 186 it will be seen that between links of the same size, made from the same bar, there were differences in strength equal to from 26 to 32 per cent. of the strength of the weaker links, the iron thus showing an irregularity in strength which excluded it from the list of suitable chain-irons.

The character of the material was so opposite to that of charcoal bloom boiler-iron, each possessing valuable qualities which were lacking in the other, that it was resolved to make some experiments by mixing the two, and the results showed plainly that, bysuch admixture, iron superior for chain-cables to either of the constituents could be produced.

PLATE XI.



Heliotype Printing Co., 211 Tremont Street, Boston.

CLOSED DOWN.

As shown by a three inch bar of iron F, bent double cold without a crack.

First experiment.—The fragments of the 1$\frac{5}{8}$'' bar which had, after having been scored, been broken by impact of an 800 foot-pound blow, were reheated and flattened, and piled with old boiler iron, in the same manner as with iron A, from which pile a bloom was hammered, and from which bloom test-bars of 2'' and 1$\frac{5}{8}$'' diameter were swaged, all being of length equal to twelve diameters. Tested by impact, after having been scored by a cut $\frac{1}{32}$'' deep, the 2'' test-pieces required *seven* and 1$\frac{5}{8}$'' *five* blows of 3,000 foot-pounds each to completely tear them in two. The original bar, which, after having been scored, broke with a blow of 800 pounds, resisted four blows of 3 000 pounds each when unscored; the effect of these blows was to close it to an angle of 105° from the horizontal, after which it was beaten by the steam-hammer until the sides touched the whole length, the iron remaining uninjured. The tensile strength of K was 57 000 pounds, that of the boiler iron 50,000 pounds, and that of the mixture 54,000 pounds.

A second experiment was made with fragments of the 1$\frac{11}{16}$'' bar, which, with tensile strength of 54,000 pounds, broke under impact after having been scored; at the second 1,200 foot-pound blow, these fragments were mixed with old boiler-iron, and four test-pieces, each of 2'' diameter and 24'' length, prepared; these resisted from *four* to *six* 3,000 foot-pound blows, tearing in two finally with a long fibrous fracture.

A third experiment was made with the fragments of 2'' bar, which were thoroughly reworked, without mixing with boiler-iron. The iron, which originally as a 2'' bar possessed tensile strength of 59,000 pounds, and was tough when unscored, brittle when scored, was not at all improved by the reworking.

The manufacturers of iron K prepared, under the instructions of the committee, a 2'' bar, which was made by combining in the pile the usual iron of which K was made with alternate layers of charcoal bloom iron, five layers in all, the center and outer ones being of charcoal bloom. At the same time they sent to us slabs of the crude iron K, which we combined with old boiler-iron in the same manner as with iron A, and hammered into a bloom, from which 2'' test-pieces were swaged; we also prepared a similar test-piece of fragments of the 2'' bar of the usual character sent to us, combined with boiler-iron. All of these bars resisted extreme tests by impact, and were of good tensile strength, viz, 54,000 to 55,000 pounds. Their record under impact tests is given on page 142.

The results of these experiments demonstrate that excellent chain-iron can be made by mills whose ordinary products cannot be considered as suitable.

One of the test-pieces made by our process having withstood *seven* blows of 3,000 foot-pounds each, and having by them been broken about one-half through, was laid aside for one year, when it was retested in the presence of a delegation of the Mining Engineers, and broke square in two at the first 3,000 foot-pound blow, other pieces from same bar having withstood *seven* and *nine* such blows, finally rupturing with long splintered fractures, as though torn in two, while the piece which was rested broke in such manner as to show that it had become very brittle.

IRON L.

Record of tests of bars by tension, Nos. 282 to 305; of links, Nos. 278 to 283; chemical analyses, Nos. 136, 138, 139, 145, 146, 184, 185.

Five bars were furnished to compete with the nine irons. All forms of test indicated that the material was steel, which analyses subsequently confirmed. The tensile strength was great; reduction of area, abrupt power of resistance to impact, very slight when scored, but fair when not scored; welding value, low; strength of links, very irregular.

The manufacturers being informed that the material was unsuitable, furnished two other bars, one of ¾" and one of ⅝", both of which withstood impact well and possessed great tensile strength. (See experiments 1, 2, and 3, "Investigation of the elevation of limit of stress," pages 116 and 117.) It was claimed that these bars made by the same process, but with less carbon, would make good chain-iron. We did not, however, test them as cable, the size and quantity being too small to enable us to obtain any results of value. Analyses confirmed the statement that the ⅝" possessed less carbon than the other bars, which ranged from .212 per cent. to .453 per cent., while the ⅝" had .042 per cent. and the ¾" .229 per cent.

IRON M.

Record of bars tested by tension, Nos. 306 to 315, and 1,047 to 1,422; by impact, Nos. 619 to 638; of links, Nos. 376 to 500; chemical analyses, 129, 133, 147, 155, 157, 158, 159, 160, 161.

A great number of tests were made upon this iron, both by physical and chemical processes. It was delivered as chain-iron at a number of different times and lots. The bars of these lots varied greatly among themselves, and the lots differed in many respects.

The iron as bars, unheated, had generally every indication of value, the tensile strength being great, although irregular, and the reduction of area and elongation under tension were good. Some of the bars resisted impact well; others broke square in two when being bent cold, with very slight closure.

As cable the iron proved very defective and irregular. The trouble with it seemed to be that if not welded at exactly the right heat (a very low one) the part of the link upon which the weld was made lost its strength by the process, and in many cases when tested the links would break through the weld at very low strains, showing little or no change of form and the fractured ends remaining unreduced in diameter. (See Fig. 5, Plate II.)

The strength of the links depending thus upon that of a section of each, which had been more or less weakened according to the degree of heat employed in welding, was very irregular, and frequently very low, ranging as follows:

1¼" sections from 123,500 to 92,000 pounds.
1$\frac{5}{16}$" sections from 117,000 to 77,000 pounds.
1⅜" sections from 136,600 to 95,000 pounds.
1½" sections from 169,000 to 140,000 pounds.
1⅝" sections from 187,000 to 125,000 pounds.
1¾" sections from 225,600 to 212,000 pounds.
1$\frac{13}{16}$" sections from 228,600 to 210,000 pounds.
2" sections from 278,000 to 255,000 pounds.

The weak links broke generally "through the weld," a form of rupture which is not a common one, for in breaking altogether 435 links but 116 broke through the weld, and of these 79 were of iron M, of which 124 links were broken. (See notes on welding, pages 150 and 151.)

A number of bolts of this iron cracked while being bent to link form, in the "link-bender."

Supplementary chemical analyses, Nos. 209 to 215, inclusive, were

PLATE XII.

IMPACT TESTS.

FIG. 1. 1 3-4 in. bar Iron C.

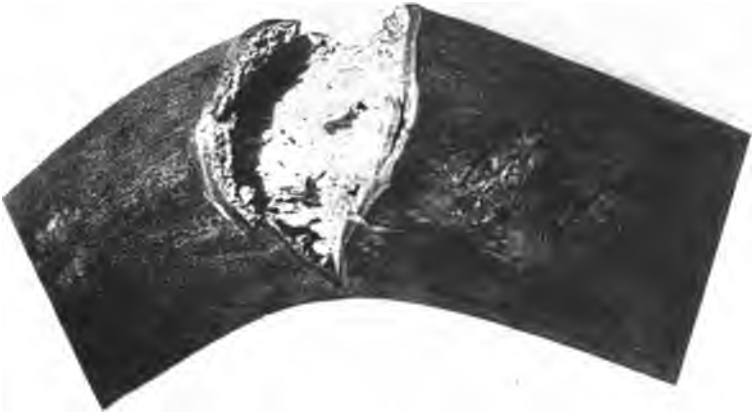
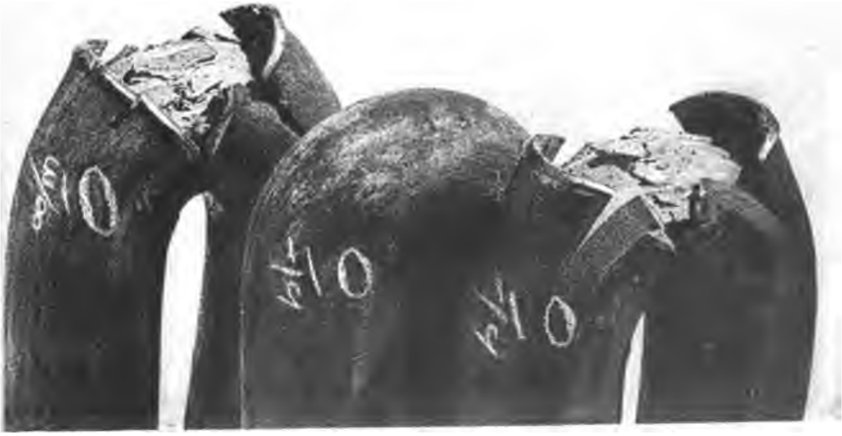


FIG. 2. Bars of Iron O.



Heliotype Printing Co., 211 Tremont Street, Boston.

THE PHENOMENA OF "BARKING" AS MANIFESTED BY IRONS C AND O.

made upon this iron, the results of which are incorporated in the comparison of physical and chemical results. They fully confirm the views expressed and deductions made from the preceding tests.

IRON N.

Record of tests of bars by tension, Nos. 896 to 911; by impact, Nos. 639 to 646; of links, Nos. 329 to 336; chemical analyses, Nos. 149 and 150.

The bars of this iron (eight in number) were furnished to the committee by a leading manufacturer as samples of "first-class chain-iron," and they were probably a fair sample of the ordinary character of such chain-iron; tested by tension the strength was generally high, change of form slight.

Under impact the large bars were very brittle, the 2″ breaking by blows when unscored, which the 1⅝″ resisted after being scored. As cable the 1⅝″ was superior to the 2″. The fault with this iron was too little work, the large bars receiving much less than the small ones. (See "Investigation of the effect of the rolls," page 39.)

IRON O.

Record of tests of bars by tension, Nos. 912 to 920; by impact, Nos. 647 to 657; of links, Nos. 337 to 345; chemical analyses, Nos. 153 and 154.

Nine bars of this iron were procured for experimental purposes, no charge being made for them.

It is in no sense of the word a chain-iron, and its merits should not be judged by its action in the form of cable.

The material was soft charcoal-bloom, and of high price.

It proved of value in our experiments upon the effect of the rolls, and as furnishing us with data as to the extreme of change of form which would occur to a link of very soft iron under stress. Although too ductile and soft for chain-iron, some of the larger sizes produced good links, while the smaller sizes were overworked for the purpose, and did not.

The average percentage of bar's strength of the 2″, 1⅞″, and 1¾″ links was 172 per cent.; that of the 1″, 1⅛″, and 1¼″ was 153 per cent.; the average tenacity of the first three sizes being 48,618 pounds, that of the last three 53,479 pounds.

Under impact this iron proved remarkably tough, and displayed the phenomena of "barking." (See Plate XII.)

IRONS P AND Px.

Record of bars tested by tension, Nos. 921 to 1,046; by impact, Nos. 658 to 680; of links, Nos. 346 to 375; chemical analyses, Nos. 151, 152.

These irons were made at the same rolling-mill, and when the physical tests were made upon P*x* it was considered to be of the same material as P, and the differences in their characteristics were attributed to variations in the mechanical processes by which they were produced, P having received one course of heating and hammering which was omitted with P*x*. Subsequent chemical analyses showed marked differences in the nature of the two irons. The results of the analyses were confirmed by a letter from the manufacturer, in which he states that he perceives that the weak point of previous lots (iron P) was the lack of transverse strength when scored, and that he has in this lot (P*x*) overcome the difficulty without essentially lowering the tensile strength.

This was effected by, first, the selection and rigid puddling of pig-iron, as free from phosphorus as possible, and then using a physic which tended to eliminate the silicon and sulphur, and then to the omission of the hammering. The result of these experiments by the manufacturer to correct the defects found at the testing-machine, was the production of a superior chain iron, which resisted impact well and welded firmly. The appearance of its fracture by impact is shown in Plate XIII, Fig. 1, and when tested as cable it developed from 159 to 169, averaging 164 per cent. of bar's strength, iron P having averaged 154 per cent. by irregular factors.

PART 2.

COMPARISON OF CHEMICAL AND PHYSICAL RESULTS.

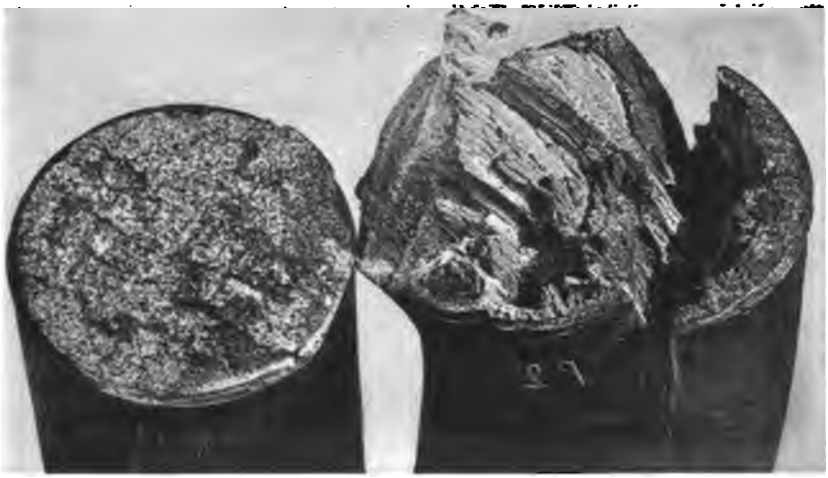
Variations in the physical qualities of iron may be due to different composition, or to different treatment in manufacture, or to both these complex causes. In order to determine the specific causes of variation, one class of altering conditions should be made to vary largely, while the other classes should be kept uniform. Then another class should be varied, and so on, until the value of each is ascertained. As all the irons under consideration were intended to have that purity and refinement which was deemed indispensable in chain cables, their chemical analyses are perhaps more important in proving that physical variations result chiefly from treatment than in pointing out the specific effects of certain ingredients. While the subject of treatment, especially the increase of strength by greater reduction in rolling, may be the more important one, it can be best appreciated after we have familiarized ourselves with the general chemical and physical characters of the irons. The typical facts are given in the following tables:

TABLE I.—*Relative values of irons in bars, in tenacity, reduction of area, and elongation, and in proportion of chain to bar.*

Order of value.	Tensile strength.		Reduction of area.		Elongation.		Proportion of tenacity of short chain to that of bar.	
	Iron.	Lbs. per sq. inch.	Iron.	Per cent.	Iron.	Per cent.	Iron.	Per cent.
1	L	66,598	O	54 2	P*x*	29.9	B	108.2
2	K	58,050	A	40.0	E 2	27.7	A	168.1
3	D 2	56,673	P*x*	48.9	P	23.2	O	105.7
4	C 2	56,001	F	48.1	O	22.7	P*x*	163.9
5	M	55,932	D 1	47.8	A	22.2	F	163.2
6	P	54,775	P	46.6	F*x* 3	22.0	D 2	158.3
7	N	54,329	F*x* 3	46.2	F	21.9	F*x* 3	157.5
8	F*x* 1	54,271	E 2	45.8	F*x* 1	21.8	C 2	156.8
9	P*x*	54,091	F*x* 1	45.3	M	21.0	N	155.8
10	D 1	53,292	E 1	45.0	D 2	20.9	P	154.5
11	F*x* 3	53,107	D 2	43.8	N	20.2	Fx 1	151.4
12	B	52,764	C 1	40.6	D 1	18.2	M	150.7
13	A	52,579	M	38.2	C 2	18.0	K	141.6
14	E 1	52,533	C 2	38.1	K	17.9		
15	E 2	52,471	K	38.0	B	17.2		
16	J	51,754	B	36.1	C 1	15.4		
17	F	51,153	N	33.0	E 1	15.3		
18	O	51,134	L	30.4	J	12.6		
19	C 1	50,765	J	25.9	L	8.3		

PLATE XIII.

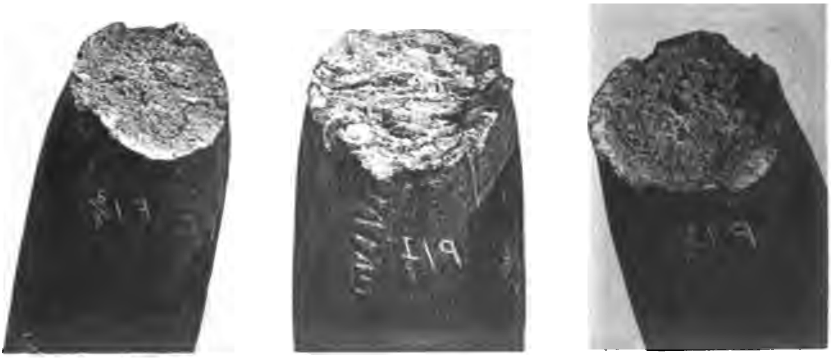
FIG. 1.



N. 1 7-8 in. Px. 2 in.

APPEARANCE OF FRACTURES OF UNDERWORKED AND THOROUGHLY WORKED IRON, BROKEN BY IMPACT.

FIG. 2.



Heliotype Printing Co., 211 Tremont Street, Boston.

APPEARANCE OF FRACTURES OF THOROUGHLY WORKED IRON, BROKEN BY TENSION.

TABLE II.—*Analyses of irons used in making chain-cables.*

Laboratory number.	Iron and size.	Sulphur.	Phosphorus.	Silicon.	Carbon.	Graphite.	Comb. carbon.	Manganese.	Copper.	Cobalt.	Nickel.	Slag and oxide of iron.	Chromium. (Sol. in dil. H. C. L.)	Chromium, oxide. (Insol. in dil. H. C. L.)	Analysis of slag.				
															Si. O$_2$.	Fe$_2$ O$_3$.	Cr$_2$ O$_3$.	Cu$_2$ O.	Mn. O.
135	A 2"	0.007	0.178	0.139	0.021	0.009	0.012	0.031	0.072	0.008	0.078	1.210	......	......	......	......	......	......	......
171	B 1 7/16"	0.008	0.231	0.156	0.015	......	......	0.017	0.038	0.047	0.037	......	......	......	......	......	......	......	......
172	C 1 1/8"	0.007	0.169	0.174	0.042	......	......	0.021	0.046	0.029	0.031	......	......	......	......	......	......	......	......
173	D 1 1/8", lot 1	0.005	0.118	0.135	0.030	......	......	0.071	0.006	0.023	0.029	......	......	......	......	......	......	......	......
186	D 1", lot 1	0.009	0.191	0.185	0.045		......	0.007	0.012	0.013	0.016	0.546	......	......	......	......	......	......	......
132	D 1", lot 2	0.005	0.239	0.171	0.028	0.008	0.020	0.029	0.008	0.023	0.028	0.570	......	......	......	......	......	......	......
174	D 1 1/2", lot 2	0.005	0.158	0.108	0.024	......	......	0.018	0.018	0.031	0.026	......	......	......	......	......	......	......	......
134	D 2", lot 2, Nov., '76	0.005	0.213	0.163	0.035	0.010	0.025	0.021	0.007	0.023	0.028	0.874	......	......	......	......	......	......	......
175	E 1 1/4"	0.013	0.181	0.159	0.018	......	......	0.021	0.054	0.044	0.042	......	......	......	......	......	......	......	......
131	F 1 1/4"	0.004	0.201	0.158	0.026	0.009	0.017	0.048	0.002	0.018	0.028	0.650	......	......	......	......	......	......	......
169	Fx 1 1/8", lot 1	0.004	0.187	0.163	0.032	......	......	0.031	0.010	0.026	0.011	......	......	......	......	......	......	......	......
170	Fx 1", lot 2	0.004	0.197	0.170	0.033	......	......	0.045	0.008	0.037	0.037	......	......	......	......	......	......	......	......
177	Fx 1 1/4", lot 3	0.004	0.193	0.170	0.028	......	......	0.039	0.006	0.042	0.042	......	......	......	......	......	......	......	......
142	J 1 7/16"	0.003	0.140	0.182	0.027	0.007	0.020	Trace.	0.004	Trace.	0.008	1.120	......	......	......	......	......	......	......
148	J 1 5/8"	0.005	0.291	0.321	0.074	0.005	0.069	0.029	0.011	0.013	0.013	1.026	......	......	......	......	......	......	......
143	J 1 11/16"	0.005	0.213	0.295	0.035	0.007	0.028	0.029	0.009	0.003	0.008	0.678	......	......	......	......	......	......	......
144	J 1 3/4"	0.003	0.213	0.303	0.051	0.008	0.043	0.007	0.011	0.013	0.008	1.230	......	......	......	......	......	......	......
137	J 1 3/8"	0.004	0.154	0.247	0.043	0.008	0.035	0.053	Trace.	Trace.	0.013	1.724	......	......	......	......	......	......	......
140	K	0.005	0.161	0.156	0.062	0.007	0.055	0.018	0.048	0.016	0.049	0.540	......	......	......	......	......	......	......
130	K 1 1/8"	0.004	0.161	0.109	0.069	0.010	0.059	0.016	0.079	0.027	0.034	0.470	......	......	......	......	......	......	......
141	K 1 3/4"	0.006	0.131	0.143	0.071	0.006	0.065	0.021	0.046	0.013	0.057	0.374	......	......	......	......	......	......	......
136	L 1 3/8"	Trace.	0.065	0.105	0.451	0.024	0.427	0.006	0.008	Trace.	0.011	0.316	......	......	......	......	......	......	......
145	L 1 7/16"	Trace.	0.073	0.098	0.328	0.022	0.306	0.015	0.018	0.013	0.013	0.192	......	......	......	......	......	......	......
146	L 1 5/8"	Trace.	0.067	0.098	0.512	0.016	0.496	0.019	0.010	0.010	0.016	0.308	......	......	......	......	......	......	......
138	L 1 11/16"	Trace.	0.074	0.070	0.212	0.013	0.199	0.014	0.006	0.010	0.013	0.453	......	......	......	......	......	......	......
139	L 1 13/16"	Trace.	0.084	0.093	0.248	0.014	0.234	0.016	0.008	0.008	0.018	0.376	......	......	......	......	......	......	......
184	L 3/4"	0.001	0.089	0.103	0.229	......	......	0.019	0.007	0.015	0.018	0.328	......	......	......	......	......	......	......
185	L 5/8"	0.004	0.232	0.175	0.042	......	......	0.040	0.066	0.026	0.020	0.068	......	......	......	......	......	......	......
155	M 1 1/4"	0.005	0.248	0.174	0.036	0.012	0.024	Trace.	0.314	0.110	0.340	1.093	......	......	0.022	0.980	0.160	None.	......
120	M 1 3/8"	0.015	0.233	0.204	0.034	0.006	0.028	0.059	0.370	0.058	0.020	0.884	......	......	......	......	......	......	......
147	M 1 5/8"	0.007	0.317	0.250	0.039	0.005	0.034	0.021	0.374	0.098	0.175	1.024	......	......	0.040	0.716	0.316	None.	......
133	M 1 1/8"	0.008	0.210	0.179	0.063	0.007	0.056	0.022	0.328	0.052	0.019	0.674	......	......	......	......	......	......	......
157	M 1 5/8"	0.000	0.221	0.104	0.064	None.	0.064	0.011	0.340	0.053	0.034	0.828	......	......	None.	0.780	0.030	None.	......
158	M 1 1/8", weld end	0.005	0.211	0.182	0.055	0.010	0.045	Trace.	0.324	0.104	0.246	0.974	0.082	0.178	0.046	0.810	0.166	None.	......
159	M 1 1/4", butt end	0.006	0.209	0.203	0.055	0.009	0.046	Trace.	0.322	0.097	0.243	1.078	0.061	0.170	0.070	0.880	0.170	None.	......
160	M 1 5/8", weld end	0.008	0.263	0.177	0.034	0.015	0.019	Trace.	0.430	0.090	0.313	1.382	0.089	0.116	0.050	1.126	0.178	None.	......
161	M 1 5/8", butt end	0.007	0.260	0.261	0.028	0.010	0.018	Trace.	0.422	0.087	0.303	1.738	0.072	0.170	0.100	1.446	0.210	None.	......

TABLE II.—*Analyses of irons used in making chain-cables*—Continued.

Laboratory number.	Iron and size.	Sulphur.	Phosphorus.	Silicon.	Carbon.	Graphite.	Comb. carbon.	Manganese.	Copper.	Cobalt.	Nickel.	Slag and oxide of iron.	Chromium. (Sol. in dil. H. C. L.)	Chromium, oxide. (Insol. in dil. H. C. L.)	Analyses of slag.				
															$Si. O_2$.	$Fe_2 O_3$.	$Cr_2 O_3$.	$Cu_2 O$.	Mn. O.
213	M 1¼"	0.010	0.207	0.173	0.036	....	....	0.013	0.320	0.079	0.236	1.616	....	....	0.088	1.408	0.130	None.	0.007
212	M 1 5/16"	0.017	0.125	0.138	0.063	....	....	0.117	0.062	0.026	0.023	0.580	....	....	0.060	0.442	0.032	Trace.	0.041
211	M 1⅜"	0.002	0.195	0.154	0.045	....	....	0.013	0.442	0.060	0.026	1.182	....	....	0.028	1.138	0.012	None.	0.012
210	M 1⅝"	0.003	0.238	0.155	0.032	....	....	0.014	0.370	0.055	0.026	0.720	....	....	0.010	0.678	0.050	0.001	Trace.
214	M 1¾"	0.011	0.166	0.187	0.053	....	....	0.012	0.498	0.047	0.026	0.994	....	....	0.076	0.902	Trace.	Trace.	0.004
215	M 1 13/16"	0.010	0.217	0.180	0.035	....	....	0.012	0.292	0.052	0.029	1.064	....	....	0.098	0.938	Trace.	None.	0.004
209	M 2"	0.005	0.237	0.173	0.055	....	....	0.017	0.420	0.038	0.0[illegible]3	0.840	....	....	0.024	0.808	0.022	Trace.	Trace.
149	N 1⅛"	0.004	0.190	0.159	0.055	0.004	0.051	0.026	0.036	0.026	0.018	1.258	....	....	....	....	....	....	....
150	N 2"	0.006	0.192	0.169	0.028	0.008	0.020	0.050	0.028	0.031	0.028	2.262	....	....	....	....	....	....	....
153	O 1"	0.004	0.067	0.065	0.045	0.007	0.038	0.007	0.046	0.033	0.034	1.168	....	....	....	....	....	....	....
154	O 1¾"	0.005	0.078	0.073	0.042	0.009	0.033	0.005	0.046	0.034	0.037	0.974	....	....	....	....	....	....	....
151	P 1"	0.009	0.250	0.182	0.033	0.008	0.025	0.033	0.081	0.037	0.057	0.848	....	....	....	....	....	....	....
452	Px 1¾"	0.001	0.095	0.028	0.066	0.009	0.057	0.009	0.008	0.029	0.023	1.214	....	....	....	....	....	....	....
156	Contract, 2 3/16"....	0.046	0.328	0.238	0.026	None.	0.026	Trace.	0.134	0.039	0.042	0.768	....	....	None.	0.716	0.040	None.	....

TABLE III.—*Summary of the principal physical and chemical characteristics of sixteen irons.*

Name of iron	L	K	D 2	C 2	M	P	N	Fx 1	Px	D 1	Fx 3	B	A	J	F	O
Number in tenacity	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Number in reduction of area	15	12	9	11	10	6	14	8	8	5	7	13	2	16	4	1
Number in elongation	16	13	9	12	8	2	10	7	1	11	5	14	4	15	6	3
Number in welding value	......	13	6	8	12	10	9	11	4	....	7	1	2	....	5	3
Number in power of resisting shocks	14	12	6	7	11	9	13	3	7	6	2	9	1	14	4	4
Percentages of—	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
Phosphorus	0.072	0.152	0.203	0.169	0.225	0.250	0.101	0.187	0.095	0.154	0.193	0.231	0.178	0.202	0.201	0.072
Silicon	0.095	0.149	0.147	0.154	0.184	0.182	0.169	0.103	0.028	0.160	0.163	0.156	0.139	0.271	0.160	0.072
Carbon	0.350	0.068	0.020	0.042	0.044	0.033	0.055	0.032	0.066	0.033	0.032	0.015	0.002	0.036	0.026	0.048
Copper	0.009	0.058	0 011	0.046	0.353	0.081	0.082	0.010	0.008	0.014	0.006	0.038	0.172	0.009	0.002	0.046
Manganese	0.014	0.022	0.030	0.021	0.020	0.033	0.038	0.031	0.009	0.084	0.039	0.017	0.031	0.023	0.048	0.006
Cobalt	0.008	0.019	0.026	0.029	0.070	0.037	0.029	0.026	0.020	0.023	0.042	0.047	0.068	0.006	0.018	0.032
Nickel	0.014	0.040	0.027	0.031	0.132	0.057	0.028	0.013	0.023	0.028	0.042	0.037	0.078	0.010	0.028	0.031
Slag	0.331	0.455	0.722	....	1.044	0.848	1.760	....	1.214	0.546	....	....	1.210	1.156	0.650	1.071

NOTE.—The welding values of D 1, J, and L are omitted, as there were no short chains made from them. D 1 welded well, and J and L poorly. The percentages are averages, when more than one analysis was made. Lab. Nos. 184, 185, 156, and 175 are omitted, there having been no short chains of the iron tested.

Table I. Relative values of irons in bars, in tenacity, reduction of area, and elongation, and in proportion of chain to bar.

Table II. Analyses of the irons.

Table III. Summary of principal physical and chemical characteristics of sixteen irons.

Under the head of phosphorus the leading chemical and physical facts about each iron likely to be affected by this element are compared, and then the group of irons is considered and a conclusion is reached; under the head of silicon the irons are again gone over in a similar manner, and so on with carbon and other ingredients. A description of a few irons in which composition should have the greatest influence on strength will suffice to introduce these conclusions.

EFFECTS OF PHOSPHORUS.

Iron O.—P. 0.07, Si. 0.07, C. 0.04. Slag medium.

Chemical impurities, all very low.

The iron had been thoroughly worked.

Tenacity as bar and as link very low.

Ductility as bar and as link very high.

Welds very good.

Low phosphorus does not alone account for these qualities. Iron **F**, with P. 0.20, Si. 0.16, and C. 0.03, has about the same tenacity and welding power, and approaches the same ductility. Iron **P**, with P. 0.25, Si. 0.18, and C. 0.033, has about equal ductility, but inferior welding qualities. Seeing that the thorough working of the small bars decreased welding power, as compared with that of the less-compressed large bars, it is probable that method of manufacture is an important factor in all physical results. The effects of low phosphorus are not conspicuous.

Iron **P**.—P. 0.25, Si. 0.18, C. 0.03. Slag very low.

P. rather high, C. medium; other impurities low.

Tenacity high as bar; irregular as link.

Ductility high when not nicked; low when nicked. Welding value, medium through overwork, and possibly high P.

Iron **Px**.—P. 0.09, Si. 0.028, C. 0.66.

This iron had the highest average of good qualities of the commercial bars examined, and was the best for general construction purposes. The characteristic effects of phosphorus, might, previous to our investigation into the effects of reduction, have been considered as shown by the behavior of two specimens, one of iron **P** and one of **Px**, made in the same way, except that one course of piling and hammering was omitted from **Px**, viz:

1″ bar iron **P**, phos. 0.25, tenacity 57,807 pounds, elongation 19 per cent.

1¾″ bar iron **Px**, phos. 0.09, tenacity 54,212 pounds, elongation 24 per cent.

But this increased tenacity and decreased ductility of the smaller bar are not due to P. alone; it had Si. 0.18 against Si. 0.03, and it had more reduction in the rolls.

The difference in the tenacity of the bars of the same sizes of iron **P**, which may be considered as probably of similar composition, was nearly 5,000 pounds, while between the bars in question, of **P** and **Px**, it was but 3,600 pounds.

P. may have affected the welding qualities and the ductility, as **Px**, with much less of this element, welded much better and had greater powers of resisting sudden strains.

Iron **D.**—P. 0.18 (0.12 to 0.24), Si. 0.15, C. 0.03. Slag low.

Carbon low; other impurities medium.

Different bars very differently worked.

Tenacity high as bar link.

Ductility medium as bar and link.

Welds very good.

There are various proofs that low phosphorus, even with low silicon, do not make high ductility, and that the amount of reduction is the more important factor. For instance:

1″ bar, P. 0.24, Si. 0.17, has tenacity per square inch, 61,000 pounds; elongation, 26 per cent.

1½″ bar, P. 0.16, Si. 0.11, has tenacity per square inch, 56,000 pounds; elongation, 23 per cent.

2″ bar, P. 0.21, Si. 0.16, has tenacity per square inch, 49,146 pounds; elongation, 0.07 per cent.

The welds of the medium sized and worked bars were best, but all were good. No harmful effect of phosphorus can be traced in this iron.

Iron **B** welded best, and had P. 0.23 and C. 0.015.

Iron **F.**—P. 0.20, Si. 0.16, C. 0.03. Slag low.

Carbon low; other impurities medium.

Iron suitably worked for welding, and very uniform.

Tenacity as bar and as link very low.

Ductility high.

Welding power good.

The remarkable uniformity of this iron proves it to have been made with great care from selected materials. Why its tenacity is so low it is difficult to say on chemical grounds. The same iron, **Fx**, more worked, gives a medium tenacity, with substantially the same analysis. Iron **A**, with less P., Si., and C., is stronger. Iron **E** has lower P., the same Si., and only 0.02 C., and yet a higher tenacity.

Iron **Fx** (**F** more worked.)—P. 0.19, Si. 0.17, C. 0.03.

Ingredients substantially the same as in **F**.

Iron much more worked than **F**.

Tenacity medium in link and bar.

Ductility good.

Welding power below medium.

Iron **B.**—P. 0.23, Si. 0.16, C. 0.015.

P. rather high, Si. medium, and C. very low.

Iron not sufficiently worked for strength.

Tenacity rather low.

Ductility quite low.

Welds very good.

Notwithstanding the extremely low C., the iron was not ductile. P. may well account for this, but not for low tenacity, as some of iron **P** had more P. and much higher tenacity. Low C. may partly account for low tenacity and good welds, but small reduction seems to be an equal cause. High P. did not prevent excellent welding.

Iron **M.**—P. 0.22 (0.21 to 0.32), Si. 0.18 (0.16 to 0.26), C. 0.04, N. 0.18 (0.03 to 0.34), Cu. 0.34 (0.13 to 0.43). Slag various.

P. rather high; Si. above medium; copper and nickel high; C. rather low.

The amount of work the iron received can only be inferred from the sizes of the bars.

Tenacity considerably above average.

Ductility average.

Welds weak.

The character of this iron is so complex, and its physical character varies so much in the same-sized bars, that no satisfactory analysis of the data can be made. It seems certain, from a comparison of the tables, that neither copper, nickel, cobalt, nor slag materially affected strength. The effects of these ingredients on welding will be considered under another head.*

Conclusions about phosphorus.—The best of these irons average P. 0.09 to 0.20. The extreme limits are 0.065 and 0.317. A soft boiler-plate steel might have the former amount; the latter would give high tenacity and brittleness to even a low-carbon steel. The investigations have been made so difficult by the chemical similarity and general purity of most of the irons, and by their various degrees of reduction in rolling, that the effect of phosphorus cannot be independently traced. While special bars having chemical and structural conditions otherwise similar seem to be increased in tenacity and brittleness by high phosphorus, other bars low in this element are not the mildest.

The phosphorus (average in each iron) runs very irregularly, as follows, beginning with the highest of the following physical values: *Tenacity*, 0.72, 0.15, 0.20, 0.17, 0.22, 0.25, 0.19, 0.19, 0.09, 0.15, 0.19, 0.23, 0.18, 0.20, 0.20, 0.07. *Reduction of area*, 0.07, 0.18, 0.09, 0.20, 0.15, 0.25, 0.19, 0.19, 0.20, 0.22, 0.17, 0.15, 0.23, 0.19, 0.07, 0.20. *Elongation*, 0.09, 0.25, 0.07, 0.18, 0.19, 0.20, 0.19, 0.22, 0.20, 0.19, 0.15, 0.17, 0.15, 0.23, 0.20, 0.07.

It may be generally stated that phosphorus 0.10, with carbon about 0.03 and silicon under 0.15, gave the best chain-cable irons of this group. One of the best irons, however. had P. 0.23, although low tenacity and high ductility are the chief requirements of such irons.

The effects of the different constituents on welding will be considered under that head.

EFFECTS OF SILICON.

See foregoing descriptions of irons **O**, **P**, **F**, and **M**.

The iron **F**, which is among the highest in silicon, did this element cause the very low tenacity despite the fair amount of P. (0.20)? If so, Si. must affect tenacity more than it affects ductility. But this is not the fact. In iron **J**, ductility as well as tenacity is reduced very low by high Si. (0.27).

Iron **J.**—Si. 0.27 (0.18 to 0.32), P. 0.20, C. 0.35. Slag average.
Silicon high; other impurities medium.
Iron not overworked.
Tenacity very low in bar and link.
Ductility very low in bar and link.
Weld rather bad.

There was no apparent chemical or physical cause for this low strength, except excessive silicon. Under sledge blows the bars split as often as they broke off, and the faces of the fracture were like layers of charcoal, although both carbon and slag were medium.

Conclusions about Silicon.—No ingredient of *steel* is less understood than this one. The technical managers of the Terrenoire Works in France, who have been notably successful in their steel manufactures founded on chemical induction, especially in the manufacture of sound steel castings which contain a large amount of Si., believe that this ingredient, up to the amount contained in most of the irons we are considering, does not decrease the tenacity or ductility of steel. And it is true that good steels are made by various processes with as much as 0.20 Si. It is believed by the Terrenoire managers that silica is the cause of the bad effects usually attributed to silicon. The table of analyses will show that, in this case, the ore has not been mistaken for the metal. The slag, which contains the silica, has been separately determined. Why wrought iron should differ from steel in respect of the effects of Si. we have not so far been able to determine, if, indeed, it does so differ. It can only be said, with reference to this series of experiments, that there is an apparent decrease of strength due to an excess of this element, while the effects of medium amounts of it are overshadowed by larger causes. The extremes of Si. were 0.028 and 0.321. In the best irons it averaged about 0.15. It ran as follows, with a regularly decreasing order of value: In *Tenacity*, 0.09, 0.15, 0.15, 0.15, 0.18, 0.18, 0.17, 0.16, 0.03, 0.16, 0.16, 0.16, 0.14, 0.27, 0.16, 0.07. *Reduction of area*, 0.07, 0.14, 0.03, 0.16, 0.16, 0.18, 0.16, 0.16, 0.15, 0.18, 0.15, 0.15, 0.16, 0.17, 0.09, 0.27. *Elongation*, 0.03, 0.18, 0.07, 0.14, 0.16, 0.16, 0.16, 0.18, 0.15, 0.17, 0.16, 0.15, 0.15, 0.16, 0.27, 0.09.

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* Chromium occurs only in iron M, four analyses of which show Cr. 0.061 to 0.089. As this element is known to increase the tenacity of steel, it may have brought iron M up to a good standard of tenacity without helping its other structural qualities. These experiments give no absolute evidence as to the effects of chromium, but it may be said that when mere tenacity is made the criterion of fitness, an iron like M may be found which will meet *that* requirement and still prove untrustworthy for cables.

EFFECTS OF CARBON.

See foregoing remarks on iron B, in which C. is extremely low.

Iron L.—C., average 0.35, highest 0.51; P., 0.10; Si., 0.10. Slag low.

Carbon very high; other impurities quite low.

Tenacity as bar highest.

Ductility as bar and link lowest.

Welding power most imperfect, decreasing as C. increases.

The following table, from a paper by William Hackney, esq.,[a] is valuable in this connection, as showing the amounts of C. in various well-known brands of wrought iron and steel:

Percentages of carbon in some varieties of iron and steel.

SERIES OF THE IRONS.

Description.	Percentage of carbon.
Soft puddled iron	trace*
Armor plates	0.016† 0.033† 0.044†
Iron rail	0.09‡
Lowmoor boiler-plate	0.10‡
Staffordshire boiler-plate	0.19†
Russian bar-iron	0.272† 0.340†
Swedish iron bar	0.054† 0.087† 0.386†
Steely puddled iron	0.30 to 0.40‡
Iron made by Catalan process direct from the ore	traces† 0.420†
Soft puddled steel	0.501†
Puddled steel rail	0.55†
Hard puddled steel	1.380†

SERIES OF THE STEELS.

Description.	Percentage of carbon.
Extra soft Fagersta Bessemer steel	0.085§
Extra soft Dowlais Bessemer steel	0.135‖
Crewe boiler-plate steel, Bessemer process	0.22 to 0.24¶
Locomotive crank-axles, Seraing Bessemer steel	0.31‡ 0.49‡
Locomotive crank-axle, by Vickers, Sheffield	0.46*
Rails and tires	0.30 to 0.50
Bessemer spring-steel	0.45 to 0.55‡
Crucible steel:	
For masons' tools	0.6*
For chipping chisels	0.75*
Crank-axle (by Krupp)	1.05‡
Gun (by Krupp)	1.18†
For flat files	1.20*
Forged Indian wootz	1.645†

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[a] Read before the Institution of Civil Engineers, London, April. 1875.

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§ D. Forbes. ‖ Snelus. ¶ F. W. Webb.

TABLE II.—*Analyses of irons used in making chain-cables.*

Laboratory number.	Iron and size.	Sulphur.	Phosphorus.	Silicon.	Carbon.	Graphite.	Comb. carbon.	Manganese.	Copper.	Cobalt.	Nickel.	Slag and oxide of iron.	Chromium. (Sol. in dil. H. C. L.)	Chromium, oxide. (Insol. in dil. H. C. L.)	Analysis of slag.				
															Si. O_2.	Fe_2O_3.	Cr_2O_3.	Cu_2O.	Mn. O.
135	A 2"	0.007	0.178	0.139	0.021	0.009	0.012	0.031	0.072	0.008	0.078	1.210	......	......	......	......	......	......	......
171	B 1 7/16"	0.008	0.231	0.156	0.015	......	......	0.017	0.058	0.047	0.037	......	......	......	......	......	......	......	......
172	C 1⅛"	0.007	0.169	0.154	0.042	......	......	0.021	0.046	0.029	0.031	......	......	......	......	......	......	......	......
173	D 1⅛", lot 1	0.005	0.118	0.135	0.030	......	......	0.071	0.006	0.023	0.029	......	......	......	......	......	......	......	......
186	D 1", lot 1	0.009	0.191	0.185	0.045	......	......	0.097	0.012	0.023	0.016	0.546	......	......	......	......	......	......	......
132	D 1", lot 2	0.005	0.239	0.171	0.028	0.008	0.020	0.029	0.008	0.023	0.028	0.570	......	......	......	......	......	......	......
174	D 1⅛", lot 2	0.005	0.158	0.108	0.024	......	......	0.018	0.018	0.031	0.026	......	......	......	......	......	......	......	......
134	D 2", lot 2, Nov., '76	0.005	0.213	0.163	0.035	0.010	0.025	0.021	0.007	0.023	0.028	0.874	......	......	......	......	......	......	......
175	E 1¼"	0.013	0.181	0.150	0.018	......	......	0.021	0.054	0.044	0.042	......	......	......	......	......	......	......	......
131	F 1½"	0.004	0.201	0.158	0.026	0.009	0.017	0.048	0.002	0.018	0.028	0.650	......	......	......	......	......	......	......
169	Fx 1⅛", lot 1	0.004	0.187	0.163	0.032	......	......	0.031	0.010	0.026	0.013	......	......	......	......	......	......	......	......
176	Fx 1", lot 2	0.004	0.197	0.170	0.033	......	......	0.045	0.008	0.037	0.037	......	......	......	......	......	......	......	......
177	Fx 1¼", lot 3	0.004	0.193	0.170	0.028	......	......	0.039	0.006	0.042	0.042	......	......	......	......	......	......	......	......
142	J 1 7/16"	0.003	0.140	0.182	0.027	0.007	0.020	Trace.	0.004	Trace.	0.008	1.120	......	......	......	......	......	......	......
148	J 1⅝"	0.005	0.291	0.321	0.074	0.005	0.029	0.029	0.011	0.013	0.013	1.026	......	......	......	......	......	......	......
148	J 1 11/16"	0.005	0.213	0.295	0.035	0.007	0.028	0.029	0.009	0.003	0.008	0.678	......	......	......	......	......	......	......
144	J 1½"	0.003	0.213	0.303	0.051	0.008	0.043	0.007	0.011	0.013	0.008	1.230	......	......	......	......	......	......	......
137	J 1⅛"	0.004	0.154	0.237	0.033	0.008	0.025	0.053	Trace.	Trace.	0.013	1.724	......	......	......	......	......	......	......
140	K	0.005	0.161	0.156	0.062	0.007	0.055	0.018	0.048	0.016	0.049	0.540	......	......	......	......	......	......	......
130	K 1½"	0.004	0.161	0.109	0.069	0.010	0.059	0.016	0.079	0.027	0.024	0.470	......	......	......	......	......	......	......
141	K 1¾"	0.006	0.131	0.143	0.071	0.006	0.065	0.021	0.016	0.013	0.057	0.374	......	......	......	......	......	......	......
136	L 1½"	Trace.	0.065	0.105	0.451	0.024	0.429	0.006	0.008	Trace.	0.011	0.316	......	......	......	......	......	......	......
145	L 1 7/16"	Trace.	0.073	0.098	0.318	0.022	0.306	0.015	0.018	0.013	0.013	0.192	......	......	......	......	......	......	......
146	L 1⅝"	Trace.	0.067	0.098	0.512	0.016	0.496	0.019	0.010	0.010	0.016	0.308	......	......	......	......	......	......	......
138	L 1 11/16"	Trace.	0.074	0.090	0.212	0.013	0.199	0.014	0.006	0.010	0.013	0.452	......	......	......	......	......	......	......
139	L 1 13/16"	Trace.	0.084	0.093	0.248	0.014	0.234	0.016	0.008	0.008	0.018	0.376	......	......	......	......	......	......	......
184	L ¾"	0.001	0.089	0.103	0.229	......	......	0.019	0.007	0.015	0.018	0.318	......	......	......	......	......	......	......
185	L ⅝"	0.004	0.232	0.175	0.042	......	......	0.040	0.066	0.026	0.026	0.668	......	......	......	......	......	......	......
155	M 1¼"	0.005	0.248	0.174	0.016	0.012	0.074	Trace.	0.314	0.110	0.340	1.091	......	......	0.022	0.980	0.160	None.	......
129	M 1⅜"	0.015	0.233	0.204	0.034	0.066	0.028	0.059	0.370	0.058	0.029	0.884	......	......	......	......	......	......	......
147	M 1⅝"	0.007	0.317	0.259	0.039	0.005	0.034	0.021	0.374	0.098	0.175	1.024	......	......	0.040	0.716	0.316	None.	......
133	M 1½"	0.008	0.219	0.179	0.063	0.007	0.056	0.022	0.328	0.052	0.019	0.674	......	......	......	......	......	......	......
157	M 1⅝"	0.010	0.221	0.164	0.064	None.	0.074	0.031	0.340	0.053	0.034	0.828	......	......	None.	0.780	0.030	None.	......
158	M 1½", weld end	0.005	0.211	0.182	0.055	0.010	0.045	Trace.	0.324	0.104	0.246	0.974	0.082	0.178	0.046	0.816	0.166	None.	......
159	M 1½", butt end	0.006	0.200	0.203	0.055	0.009	0.046	Trace.	0.322	0.097	0.243	1.078	0.061	0.170	0.070	0.880	0.170	None.	......
160	M 1¾", weld end	0.008	0.263	0.177	0.074	0.015	0.019	Trace.	0.430	0.090	0.313	1.382	0.089	0.116	0.150	1.120	0.178	None.	......
161	M 1¾", butt end	0.007	0.260	0.261	0.028	0.010	0.018	Trace.	0.422	0.087	0.303	1.738	0.072	0.170	0.160	1.446	0.210	None.	......

TABLE II.—*Analyses of irons used in making chain-cables*—Continued.

Laboratory number.	Iron and size.	Sulphur.	Phosphorus.	Silicon.	Carbon.	Graphite.	Comb. carbon.	Manganese.	Copper.	Cobalt.	Nickel.	Slag and oxide of iron.	Chromium. (Sol. in dil. H. C. L.)	Chromium, oxide. (Insol. in dil. H. C. L.)	Analyses of slag.				
															$Si. O_2$.	$Fe_2. O_3$.	$Cr_2. O_3$.	$Cu_2. O$.	Mn. O.
213	M 1¼″	0.010	0.207	0.173	0.036	....	....	0.013	0.320	0.079	0.236	1.616	....	....	0.088	1.408	0.130	None.	0.007
212	M $1\frac{5}{16}$″	0.017	0.125	0.138	0.063	....	....	0.117	0.062	0.026	0.023	0.580	....	....	0.060	0.442	0.032	Trace.	0.041
211	M 1⅜″	0.002	0.195	0.154	0.045	....	....	0.013	0.442	0.060	0.026	1.182	....	....	0.028	1.138	0.012	None.	0.012
210	M 1⅝″	0.005	0.238	0.155	0.032	....	....	0.014	0.370	0.055	0.026	0.720	....	....	0.010	0.678	0.050	0.001	Trace.
214	M 1¾″	0.011	0.163	0.187	0.053	....	....	0.012	0.498	0.047	0.026	0.994	....	....	0.076	0.902	Trace.	Trace.	0.004
215	M $1\frac{7}{16}$″	0.010	0.247	0.180	0.035	....	....	0.012	0.292	0.052	0.029	1.064	....	....	0.098	0.958	Traco.	None.	0.004
209	M 2″	0.005	0.237	0.173	0.055	....	....	0.017	0.420	0.038	0.033	0.840	....	....	0.024	0.808	0.022	Trace.	Traco.
149	N 1⅛″	0.004	0.190	0.159	0.055	0.004	0.051	0.016	0.036	0.026	0.018	1.258	....	....	....	....	....	....	....
150	N 2″	0.006	0.192	0.169	0.028	0.008	0.020	0.050	0.028	0.031	0.028	2.262	....	....	....	....	....	....	....
153	O 1″	0.004	0.067	0.065	0.045	0.007	0.038	0.007	0.046	0.033	0.034	1.168	....	....	....	....	....	....	....
154	O 1¼″	0.005	0.078	0.073	0.042	0.009	0.033	0.005	0.046	0.034	0.037	0.974	....	....	....	....	....	....	....
151	P 1″	0.009	0.250	0.182	0.033	0.008	0.025	0.033	0.081	0.037	0.057	0.848	....	....	....	....	....	....	....
452	P*x* 1¾″	0.001	0.095	0.028	0.066	0.009	0.057	0.009	0.008	0.029	0.023	1.214	....	....	....	....	....	....	....
156	Contract, $2\frac{3}{16}$″....	0.046	0.328	0.238	0.026	None.	0.026	Trace.	0.134	0.039	0.042	0.768	....	....	None.	0.716	0.040	None.	....

TABLE III.—*Summary of the principal physical and chemical characteristics of sixteen irons.*

Name of iron	L	K	D 2	C 2	M	P	N	Fx 1	Px	D 1	Fx 3	B	A	J	F	O
Number in tenacity	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Number in reduction of area	15	12	9	11	10	6	14	8	8	5	7	13	2	16	4	1
Number in elongation	16	13	9	12	8	2	10	7	1	11	5	14	4	15	6	3
Number in welding value	......	13	6	8	12	10	9	11	4	....	7	1	2	....	5	3
Number in power of resisting shocks	14	12	6	7	11	9	13	3	7	6	2	9	1	14	4	4
Percentages of—	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
Phosphorus	0.072	0.152	0.203	0.169	0.225	0.250	0.101	0.187	0.095	0.154	0.193	0.231	0.178	0.202	0.201	0.072
Silicon	0.095	0.149	0.147	0.154	0.184	0.182	0.169	0.103	0.028	0.160	0.103	0.156	0.139	0.271	0.100	0.072
Carbon	0.350	0.068	0.029	0.042	0.044	0.033	0.055	0.032	0.066	0.033	0.032	0.015	0.002	0.036	0.026	0.048
Copper	0.009	0.058	0 011	0.046	0.353	0.081	0.032	0.010	0.008	0.014	0.006	0.038	0.172	0.009	0.002	0.046
Manganese	0.014	0.022	0.030	0.021	0.020	0.033	0.038	0.031	0.009	0.084	0.039	0.017	0.031	0.023	0.048	0.006
Cobalt	0.008	0.019	0.026	0.029	0.070	0.037	0.029	0.026	0.020	0.023	0.042	0.047	0.068	0.006	0.018	0.032
Nickel	0.014	0.040	0.027	0.031	0.132	0.057	0.023	0.013	0.023	0.028	0.042	0.037	0.078	0.010	0.028	0.031
Slag	0.331	0.455	0.722	....	1.044	0.848	1.760	....	1.214	0.546	....	....	1.210	1.156	0.650	1.071

NOTE.—The welding values of D 1, J, and L are omitted, as there were no short chains made from them. D 1 welded well, and J and L poorly. The percentages are averages, when more than one analysis was made. Lab. Nos. 184, 185, 156, and 175 are omitted, there having been no short chains of the iron tested.

The obvious conclusions are: 1st. That any wrought iron, of whatever ordinary composition, may be welded to itself in an oxidizing atmosphere at a certain temperature, which may differ very largely from that one which is vaguely known as a "welding heat." 2d. That in a non-oxidizing atmosphere, heterogeneous irons, however impure, may be soundly welded at indefinitely high temperatures.

These speculations may throw little light on the subject of welding. They are introduced for the purpose of indicating the direction of further inquiry and experiment, and of impressing the necessity of caution in arriving at conclusions about these irons from the limited data afforded by these experiments.

In reviewing the experiments with reference to welding, and under the precautions mentioned, let us observe:

1st. All the irons were so very low in sulphur that this ingredient could not have materially affected welding power.

2d. As we shall see in detail, farther on, the irregular differences in the working and reduction of the bars which affected all other physical properties affected this one also.

Let us first take the singularly impure iron **M**. Its surfaces were pretty well united by welding, but the iron about the weld was weakened, especially at a high heat. Of 124 ruptures of links made of this iron, 79 were through the weld, and the iron was little distorted. Of 311 ruptures of links made of other irons, but 37 were through the weld.

The 1¼″ bar of iron **M** presents an exception; it stands high on the list in welding capacity, and contains copper 0.31 (average Cu. in iron **M** 0.34). Its phosphorus, slag, and silicon are about average. But the bar is also remarkable in containing nickel 0.35 and cobalt 0.11. Did these ingredients neutralize the copper under this special treatment? No other irons contain any notable amount of them, except iron **A**, which has Co. 0.07 and Ni. 0.08; but it also has Cu. 0.17.* The welds of this iron were very strong, the links breaking oftener at the butt than at the weld.

Two links made from iron **M** were analyzed from specimens taken at the weld end and at the butt end. The weld end had been reheated and hammered twice; the butt end had not been hammered, and had received second heat only by conduction from the other end. The analyses show that silicon and slag only were materially affected by twice heating and hammering, as follows:

	Si.	Slag.
Iron M, 1½″ bar, weld end	0.182	0.998
Iron M, 1½″ bar, butt end	0.203	1.074
Iron M, 1⅜″ bar, weld end	0.177	1.388
Iron M, 1⅜″ bar, butt end	0.261	1.732

In oxodizing to silica the Si. diffused a small amount of flux, which should have helped welding by preventing oxidation or by carrying off oxide of iron, or both; but the amount was so very small in this case that its effect cannot be traced. Nor does iron **J**, in which Si. was highest (0.18 to 0.32), confirm this theory. Athough the other impurities were not high, and the iron was not overworked, it welded rather badly. The value of short chains is as follows: Best, Si. 0.16, 0.14, 0.07, 0.03, 0.16, 0.15, 0.17, 0.15, 0.17, 0.18, 0.16, 0.18, 0.15, and, including **J**, 0.27.

Phosphorus, up to the limit of ¼ per cent., had not a notable effect on welding. It was lowest in iron **O**, which welded soundly, but all impurities were low, and welding power was traced to the reduction of the bar by direct experiment. The same is true of iron **P**. Omitting one course of piling and hammering largely helped its welding power. Iron **P** welded badly, not necessarily on account of its P. 0.25; for iron **B**, with P. 0.23, and iron **D**, with P. 0.18, welded soundly. Iron **M** had high P., 0.23 (0.21 to 0.32). While its surfaces stick together pretty well, the links broke through the weld when they were made at a high heat, which may be accounted for by the fact that phosphorus increases fluidity, and hence capacity for oxidation. The value of short chains is in the following order: Best, P. 0.23, 0.18, 0.07, 0.09, 0.20, 0.20, 0.19, 0.17, 0.19, 0.25, 0.19, 0.22, 0.15.

---

* This iron may have received the copper while being rolled in a train ordinarily used for copper at the navy-yard, Washington, D. C., where it was manufactured.

Carbon notably affected welding. It ran as follows in connection with regularly decreasing welding power: Best, C. 0.015, 0.002, 0.043, 0.066, 0.026, 0.032, 0.032, 0.042, 0.055, 0.033, 0.032, 0.0044, 0.68, and, including **L**, 0.351.

The weld-steel, or steely iron, **L** (C. 0.035), when treated by the uniform method usually adopted for chain-cable irons, made the worst welds. Iron **K**, with carbon so low as 0.07, made bad welds, although it was otherwise a good average chain-iron, with a medium amount of impurity. Carbon, in a greater degree than phosphorus, promotes fluidity, hence the iron is "burned" at the ordinary welding temperatures of low-carbon irons.

Slag was highest (2.26 per cent.) in the 2″ bar of iron **N**, which welded less soundly than any other bar of the same iron, and below average as compared with the other irons. Slag should theoretically improve welding, like any flux, but its effects in these experiments could not be definitely traced.

WHAT IS LEARNED FROM CHEMICAL ANALYSIS.

So far, it may appear that little of use to the makers or the users of wrought iron has been learned. But it should be remembered that all these irons were intended to be as nearly as possible alike, and to be adapted to the peculiar use of chain-cable. The makers generally understood the necessary conditions, and every effort was made to reach this special standard of excellence. Had it been reached, the irons would have all been exactly alike in physical character, and presumably similar, although not necessarily alike in chemical character, for certain ingredients may replace others within limits which are perhaps narrow. Certainly the attempt to make all the irons conform to a well-known standard of quality was the worst possible way to ascertain the distinctive effects of the various altering ingredients. In order to make this latter determination, one series of irons should have been made as uniform as possible in all ingredients except one, for instance phosphorus, and that one should have been varied as much as possible. Another series should have been alike except in silicon, and so on through the list of altering ingredients. The series of tests which the board has undertaken on steels was devised upon this principle. It was, however, thought best, after the physical tests of these irons were completed, to subject them to analysis, in the hope that some good result would follow. This hope has been realized in an unexpected and somewhat surprising manner.

1st. The want of uniformity in the chemical composition of the *same brand of iron* is a conspicuous defect which is readily accounted for. In iron **M** silicon varied from 0.16 to 0.26; in iron **J** it varied from 0.18 to 0.32; in iron **D** phosphorus varied from 0.12 to 0.24, and in iron **J** from 0.14 to 0.29.

Starting with a uniform pig-iron, the puddling process may or may not remove a large amount of silicon, phosphorus, and carbon, according to the temperature and agitation of the bath, the "fix" used in the furnace, and from many causes under the puddler's control, and dependent on his knowledge and skill.

Such variations would be entirely inadmissible in the most common grades of steel; in fact, they could not occur in the cheap-steel processes, when using a uniform pig-iron, except by a special effort. In the Bessemer process the completion of the oxidation of silicon and carbon is obvious to the inexpert observer; in the open-hearth process unmistakable tests are taken during the operation. The character of steel can be surely predicated on the analysis of its materials; that of wrought iron is altered by subtile and unobserved causes. Should it be urged in favor of wrought iron that P. can be largely removed during its manufacture, while in the steel manufacture it cannot be, it may be answered that there is an abundance of pig-irons which do not contain much P., and it is better to be sure of a definite amount of a deleterious ingredient than to run the risk of a variable amount.

We are not prepared to show the exact effect of varying reduction on steel. Ingots of the same grade of steel, from 6″ square to 14″ square, are employed for the same sized bars; the larger ones are preferred, notwithstanding the greater cost of working them, not because small ingots will not make good bars, but because they make too much scrap. Steel depends comparatively lightly on condensation for its density, but very greatly on its being cast from a fluid state. It is a crystalline mass in both large and small ingots, and not a bundle of fibers of iron more or less compacted.

2d. This matter of varying strength due to varying reduction—the most important developed by the series of experiments—is made all the more certain and useful by the analyses; for without a knowledge of the composition of the bars and of the specific effects of different ingredients, a part of the variation now traced to reduction might have been attributed to composition.

It may be stated in general terms that, notwithstanding this attempt at uniformity, the differences in reduction in the rolling-mill from pile to bar caused as much variation in the physical qualities of these irons as did the differences in the chemical composition of the whole series of irons, excepting the steely iron L. The highest difference in tenacity, due apparently to varying reductions, is 11,969 pounds per square inch. The highest difference between the average tensional resistances of all the irons (excepting the steely iron L), due to all causes, is but 7,109 pounds. The following illustrations are more in detail:

IRON P.

	Pounds per sq. in.
Tenacity of 1″ bar (1.74 per cent. of pile) above 2″ (6.98 per cent. of pile)...	6,973
Elastic limit of 1″ bar (1.74 per cent. of pile) above 2″ (6.98 per cent. of pile).	7,352

IRON F.—SECOND LOT.

Tenacity of 1⅛″ bar (2.76 per cent. of pile) over 2″ (5.23 per cent. of pile)....	4,698
Elastic limit of 1⅛″ bar (2.76 per cent. of pile) over 2″ (5.23 per cent of pile).	3,227

IRON F.—THIRD LOT.

Tenacity of ¼″ bar (1.60 per cent. of pile) over 2¼″ (6.13 per cent. of pile) per square inch	9,656

	Pounds.
Tenacity of ⅝″ bar (3.68 per cent. of pile) over 4″ (15.70 per cent. of pile) per square inch	7,786
Elastic limit of ⅝″ bar (3.68 per cent. of pile) over 4″ (15.70 per cent. of pile) per square inch	15,045
Tenacity of 1″ bar (3.14 per cent. of pile) over 4″ (15.70 per cent of pile) per square inch	4,806

IRON N.

Tenacity of 1¼″ bar (6.62 per cent. of pile) above 2″ (11.36 per cent. of pile) per square inch	4,395

IRON A.

Tenacity of 1″ bar (3.14 per cent. of pile) over 2″ (8.72 per cent. of pile) per square inch	4,519

IRON D.

Difference in phosphorus in 1″ and 2″ bars, 0.028; other ingredients about alike.

Tenacity of 1″ bar over 2″ bar	11,969

The following are comparative results of composition:

COMPARATIVE TENACITY PER SQUARE INCH.

On iron highest in average qualities over the one lowest in impurities	3,136
Of most tenacious steely iron (carbon 0.35) over least tenacious (carbon 0.04)	15,464

3d. The variation of welding power by reduction, in a greater degree than by composition, has already been shown in detail. Chemical analyses were necessary to establish this fact.

4th. To the steel-maker and user it will appear somewhat remarkable that phosphorus may run up to nearly a quarter of 1 per cent., in good chain-cable irons, when it is considered that low tenacity and high ductility are the essential features of such irons, and that the effect of this ingredient is to produce exactly opposite results. Suitable working probably counterbalanced its effects.

5th. The comparison of chemical and physical results suggests a number of experiments which would go far to settle vexed questions and improve the practice, especially with regard to welding.

(1.) Regarding slag, it has been shown that a larger amount is sometimes found in a well-worked than in a less-reduced iron, and that its effects are uncertain. Experiments should be arranged to show what composition of slags will readily come out of the pile in rolling; whether 2-high or 3-high trains will best remove them, and how much and what kind of slag affects strength and welding. A stable oxide of iron, which would probably do the most harm, could be formed by blowing superheated steam upon red-hot bars before piling. It might be proved that very fusible slags, or fluxes, should be placed in the pile to protect surfaces from oxidation and to wash away less fusible impurities.

(2.) It has already been suggested that special irons, having respectively a certain ingredient in excess and the others low and uniform, should be made, in order to ascertain in a conspicuous manner the physical effects of the various ingredients.

(3.) Referring to a previous recapitulation of remarks on welding: The effects of very different temperatures on irons varying in composition, as compared with that uniformly high temperature usually known as a "welding heat," should be much more carefully ascertained. And the effects, and more especially the means of welding in a non-oxidizing flame, where mobility of surfaces can be got without "burning," should be made the subject of elaborate experiments. The excellent welding of a heterogeneous mass of steel and iron, protected from oxidation by being placed in an iron box which will stand a high heat, has been referred to. The system of gas-welding, by which Mr. Bertram welded boilers, at Woolwich, twenty years ago, has since been in regular use by the Butterly Company, in England, for joining the members of wrought-iron beams of large section. It should seem within the power of modern engineering and chemistry to provide means for the perfection in a non-oxidizing atmosphere of welds like those of ships' cables and bridge links, upon which hang so many lives and so much treasure.

CONCLUSIONS DERIVED FROM A COMPARISON OF CHEMICAL AND PHYSICAL RESULTS.

I. Although most of the irons under consideration are much alike in composition, the hardening effects of phosphorus and silicon can be traced, and that of carbon is very obvious. Phosphorus up to 0.10 per cent. does not harm and probably improves irons containing silicon not above 0.15 and carbon not above 0.03. None of the ingredients, except carbon, in the proportions present, seem to very notably affect welding by ordinary methods.

II. The strength of wrought iron and its welding power by ordinary methods are varied more by the amount of its reduction in rolling than by its ordinary differences in composition. Uniform strength may be promoted by uniform reduction, but only at such increased cost of manufacture that the practice is not likely to obtain. Therefore, the reduced strength of large bars made by ordinary methods should be considered in designing machinery and structures.

III. In accordance with these facts, the United States Test Board has shown, by trial, the unsafety of the Admiralty proof tables for chain-cable, and has prepared new ones, and also new tables of the strength of different-sized bars. The Board has demonstrated that the tenacity of 2″ bar for chain cable should be between 48,000 and 52,000 pounds per square inch, and of 1″ bar between 53,000 and 57,000 pounds, and that stronger irons than these make worse cables because they have low ductility and welding power.

IV. Chemical analyses, made in connection with physical tests, are indispensable to conclusions about either the character or treatment of iron. In this series of experiments the demonstration that strength is dependent on reduction is made more definite and useful by the analyses.

V. Analyses also prove that the same brand of wrought iron may be heterogeneous in composition, and they emphasize the previously known fact that wrought-iron-making processes as compared with the cheap steel processes necessarily give an uncertain character to the former material, while to the latter the desired quality may be imparted with certainty and uniformity.

VI. The ordinary practice of welding is capable of radical improvement; the fact has been fully demonstrated; the means should be made the subject of complete experiments. The perfection of means for welding in a non-oxidizing atmosphere would seem to be the promising direction of improvement.

In submitting the foregoing history of their experiments, and deductions therefrom, the committees recognize the fact that much still remains to be done before either of the investigations can be considered complete. But having exhausted the time and means at their disposal, they are compelled to submit the results as far as accomplished.

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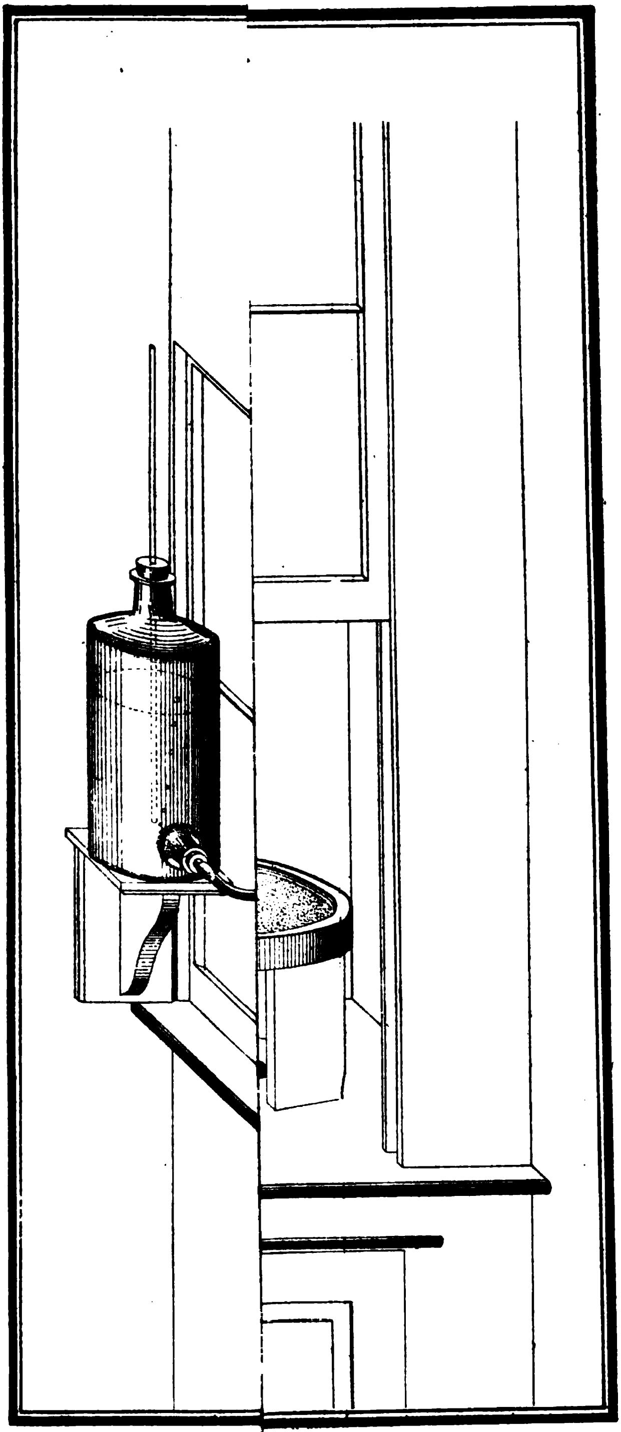

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METHODS

USED IN

THE ANALYSIS

OF

IRON AND STEEL, COPPER,

AND

THE ALLOYS OF COPPER, ZINC, AND TIN.

BY

ANDREW A. BLAIR,

CHEMIST TO THE UNITED STATES BOARD APPOINTED TO TEST IRON, STEEL, AND OTHER METALS.

◆

WASHINGTON:
GOVERNMENT PRINTING OFFICE.
1882.

REPORT OF THE CHEMIST OF THE BOARD.

WATERTOWN ARSENAL, *June* 4, 1878.

SIR: I have the honor to transmit herewith a detailed account of the methods used by me for the analysis of the samples of iron, steel, copper, and its various alloys, required for the use of the Board.

Most of the methods are well known, and in only a few cases can I claim any originality.

As will be seen by the descriptions, my first object has been extreme accuracy, while rapidity and ease of manipulation have been considered only when entirely consistent with this prime essential.

The necessity for this will be apparent to any one who understands the ends sought by the Board; and it has been my constant endeavor to keep these ends fully in view at every step.

If in any respect I have failed, the fault has been my own, for the Board in no case denied me any facility or convenience necessary for the successful prosecution of the work.

I am, very respectfully, your obedient servant,

ANDREW A. BLAIR,
Chemist to the Board.

Col. T. T. S. LAIDLEY,
President United States Board appointed to test iron, steel, and other metals.

METHODS USED IN THE ANALYSIS OF IRON AND STEEL, COPPER, AND THE ALLOYS OF COPPER, ZINC, AND TIN. BY ANDREW A. BLAIR, CHEMIST TO THE BOARD.

IRON AND STEEL.

SULPHUR.

Weigh 10 grammes of borings or drillings, free from lumps, into the previously dried flask A, Plate 1. Close it with a rubber stopper fitted with the funnel tube *a* and a delivery tube. The small flask B serves as a condenser, and is fitted with an inlet tube reaching almost to the surface of a small amount of water in the bottom of the flask, a safety tube, *b*, dipping just below the surface of the water (on the top of which the rubber cap *c* is placed when air is being drawn through the apparatus), and an exit tube connected with the first of the two wide-mouthed bottles D. This flask stands in a vessel, C, which is filled with ice-water to cool the flask when it becomes heated. The bottles D are about half filled with a dilute solution of oxide of lead in potassium hydrate. Close the stop-cock of the funnel tube, and pour into the bulb, which is of about 100 c. c. capacity, a mixture of 50 c. c. strong $H\,Cl$ and 50 c. c. water. Place the flask on the tripod, and connect the apparatus. By means of the stop-cock admit the acid very gradually into the flask, so that the evolved gas shall pass through the bottles D at the rate of about 4 or 5 bubbles a second. When all the acid has passed through the stop-cock, close it and pour into the bulb a few c. c. of water, which will serve to carry down any small amount of gas that may collect below the stop-cock during the subsequent heating. Apply heat very gradually, keeping the rate of evolution of the gas uniform, until the liquid in the flask is heated to boiling. Boil from 15 to 30 minutes, then connect the aspirator bottles E, open the stop-cock, close the safety tube *b* with the cap *c*, and remove the source of heat.

The apparatus now appears as in the cut, Plate 1. Draw through 2 or 3 liters of air, disconnect the apparatus, and wash the precipitated sulphide of lead in the bottle D into a No. 2 Griffin's beaker. Clean out the tube and bottle with a small piece of filter paper, and add it to the precipitate. Collect the precipitate on a small filter, wash several times with hot water, and while still moist throw the filter and precipitate back into the beaker, in which has been placed just an instant previously some powdered $K\,Cl\,O_3$ and about 10 c. c. strong $H\,Cl$. Digest it for a few minutes, and then dilute the acid with about twice its bulk of warm water; if necessary, add more $K\,Cl\,O_3$, and place the beaker on the water bath until the liquid is almost colorless. Then, without diluting, filter into a No. 1 beaker, and wash the residue several times with hot $H\,Cl$ and water (1—3), and finally with hot water. Evaporate the filtrate to small bulk, add barium chloride, then a slight excess of ammonium hydrate, and acidulate the solution slightly with $H\,Cl$. Boil it a few minutes, and place the beaker on the water bath over night. Filter the precipitated $Ba\,S\,O_4$, wash with dilute $H\,Cl$, and finally with hot water, dry, ignite and weigh as $Ba\,S\,O_4$. It contains 13.72 per cent. of sulphur.

The results obtained by this method are always slightly higher than those by the oxidation method. Many steels which by the latter give no trace, by the former give appreciable amounts of sulphur. This method requires less time than the other, and duplicate results agree perfectly.

GRAPHITE.

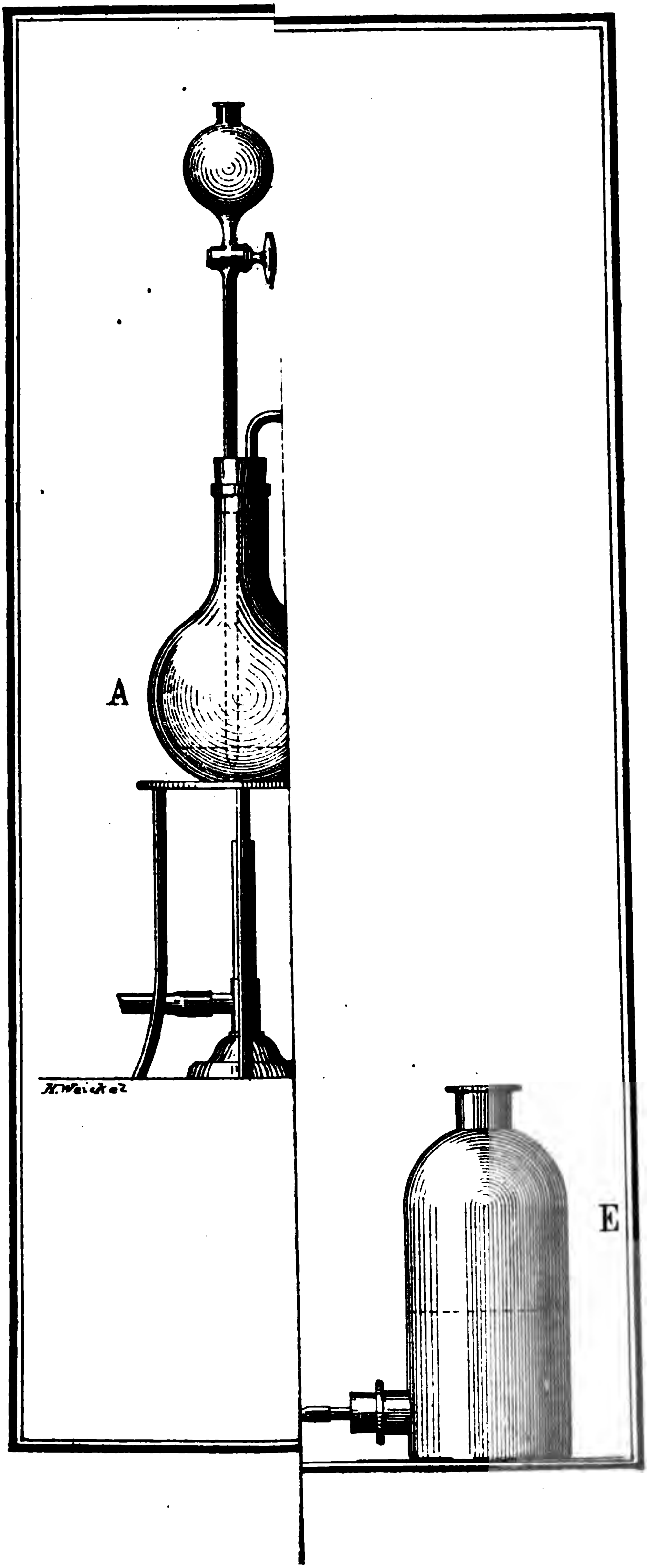
To determine the small amount of graphite contained in most steels, the residue in the flask from the determination of sulphur may be taken. For this purpose wash it out into a beaker, filter on an asbestos filter, and wash with dilute $H\,Cl$ and hot water. Pour on a hot solution of potassium hydrate, sp. gr. 1.27, and wash again with hot water, alcohol, and finally with ether; transfer the contents of the filtering tube to a platinum boat, dry at 100° C., and burn the graphite in a tube in a current of oxygen, as in the determination of total carbon, collecting and weighing the $C\,O_2$ in a potash bulb.

With pig-iron it is difficult to wash all the graphite out of the flask without using a large amount of water; it is moreover more convenient to operate on a smaller amount, say from 1 to 3 grammes of the drillings. In this case, weigh the drillings (lumps are better, as the graphite has so great a tendency to fly off and cause loss when finely divided) into a beaker, and digest with $H\,Cl$ and water, equal parts. When perfectly dissolved, boil the solution for half an hour, filter, and treat the insoluble matter exactly as in the former case. This method for determining graphite is not perfectly satisfactory, but is undoubtedly the best method known at present.

SILICON AND PHOSPHORUS.

Treat 5 grammes of drillings in a beaker of at least 400 to 500 c. c. capacity, covered with a watch glass, with 400 c. c. of strong $H\,N\,O_3$.

Plate I.



Check the action if too violent by standing the beaker in cold water, or accelerate it if necessary by heat and by adding a drop or two of $H\,Cl$ from time to time, until solution is complete. Wash and remove cover, evaporate solution to dryness, add 35 c. c. $H\,Cl$, cover and heat until all iron has dissolved, remove cover and evaporate to dryness; finally heat on sand bath, at from 120° to 130° C., until all smell of acid has disappeared. Allow to cool gradually, and redissolve in 35 c. c. $H\,Cl$, and when solution is complete add about 50 c. c. water, and boil for half an hour, to convert any pyrophosphate that may have been formed to orthophosphate. Evaporate off excess of acid, dilute, filter off $Si\,O_2$, wash filter with dilute $H\,Cl$, and finally with hot water. Dry and ignite the filter containing the $Si\,O_2$ in a platinum crucible. Weigh and treat the residue with dilute $H\,Fl$ and a drop or two of $H_2\,S\,O_4$, or better add water and $H_2\,S\,O_4$, and saturate the water with $H\,Fl$ gas, generated from cryolite and $H_2\,S\,O_4$ in a platinum still. When solution is complete, evaporate to dryness, heat until fumes of $S\,O_3$ have disappeared, and finally raise the crucible for an instant to a dull red, cool and weigh. The difference is $Si\,O_2$.

In the case of pig irons it is better to fuse the ignited residue with eight parts of $Na_2\,C\,O_3$ and a little $K\,N\,O_3$, dissolve in water, acidulate with $H\,Cl$, evaporate to dryness, and heat to expel all $H\,Cl$; redissolve in $H\,Cl$ and water, filter, wash well, dry, ignite and weigh, and treat with $H\,Fl$ as in the case of steel.

This, of course, gives the total $Si\,O_2$, from which subtract the $Si\,O_2$ in the slag (see Estimation of Slag and Oxide of Iron), and the difference is $Si\,O_2$ which existed as Si in the iron and steel, and which contains 46.67 per cent. of Si. Dilute the filtrate from the silica in a No. 6 beaker to about 400 c. c., add sufficient $N\,H_4\,H\,S\,O_3$* to reduce all the iron to ferreous salt, heat to boiling, neutralize with $N\,H_4\,H\,O$ (as deoxidation is not complete in a very acid solution), and when the solution is colorless add about 5 c. c. strong $H\,Cl$, and boil off all smell of $S\,O_2$. Cool as quickly as possible, and when thoroughly cold add dilute ammonia until a slight permanent green precipitate remains after stirring; redissolve this with a few drops of acetic acid No. 8, and add from 1 to 2 c. c. of strong ammonium acetate. Dilute to about 750 c. c. with hot water, and if the precipitate formed is white add very dilute solution of ferric chloride (containing about 10 m. grms. of $Fe_2\,O_3$ to the c. c.) drop by drop until the precipitate has a faint reddish tinge. Heat to boiling, and filter rapidly,† keeping the solution hot, wash several times with hot water, dissolve on the filter with $H\,Cl$, allowing the solution to run into a small clean beaker, dissolve any precipitate that adheres to the large beaker with $H\,Cl$, pour it through the filter, and wash the filter well with hot water. Evaporate the solution almost to dryness, add enough citric acid to keep the iron in solution (from 2 to 3 grammes dissolved in 5 c. c. water is generally enough unless the iron precipitate is very bulky), then magnesia mixture and excess of $N\,H_4\,H\,O$. Stir just enough to mix the solution, but avoid touching the sides of the beaker with the rod, and cool in ice-water. When thoroughly cold, stir well, and stand aside for a few minutes. Then if the precipitate has not begun to appear, stir until it does, stir afterwards several times at intervals of from 10 to 15 minutes, and stand aside overnight. The solution should not exceed 20 or 30 c. c. in bulk.[*] Filter the precipitated ammonium-magnesium-phosphate on a small close filter without attempting to remove the adhering precipitate from the beaker, wash several times with weak ammonia water, dry and ignite in a platinum crucible. Dissolve the precipitate in the crucible in H Cl and water, equal parts, cover the crucible with a small watch-glass, and boil carefully for about 30 minutes, to convert the pyro- to orthophosphate. Pour the solution back into the beaker just used, and wash out the crucible into it. This will dissolve any precipitate which may have adhered to the sides of the beaker previously. Filter into a small beaker, wash the filter well, evaporate to small bulk, add 2 or 3 drops magnesia mixture, a small crystal of citric acid and excess of ammonia. Cool, and precipitate carefully as before, allow to stand overnight if the precipitate is small, filter, wash with ammonia water, dry, ignite and weigh as $Mg_2 P_2 O_7$, which contains phosphorus 27.93 per cent., or phosphoric acid 63.96 per cent.

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* $N\,H_4\,H\,S\,O_3$ is best made by passing washed $S\,O_2$ (made by heating copper filings in a flask with strong $H_2\,S\,O_4$) into strong aqueous ammonia until the white basic salt first formed is redissolved, and the yellow oily solution smells strongly of $S\,O_2$. Of this solution 8 c. c. will deoxidize 5 grammes iron.

† The filtrate should come through perfectly clear, and subsequent cloudiness is of no importance; but care should be taken that it does not come through cloudy, as sometimes happens when there is a small tear in the filter. This cloudiness may be mistaken for the cloudiness caused by subsequent oxidation.

The first precipitate of $Mg_2 (N H_4)_2 P_2 O_8$ is apt to contain a little silica, oxide of iron, and magnesium hydrate, the latter especially if the precipitate is large. All of these sources of error are eliminated by the ignition, solution, and subsequent filtration. One can get rid of the two latter by dissolving the precipitate on the filter, instead of igniting it; but the silica, being often in a gelatinous condition, sometimes dissolves in the acid and is carried down on the addition of ammonia with the precipitate of ammonium-magnesium-phosphate. Ignition is consequently the safer plan.

COPPER.

Weigh out 5 grammes of borings into a beaker of about 750 c. c. capacity, and dissolve in a mixture of 30 c. c. H Cl and 15 c. c. $H N O_3$. When solution is complete, boil for some minutes,[†] dilute and filter through a ribbed filter, wash well, heat the filtrate almost to boiling, add 10 c. c. $N H_4 H S O_3$, nearly neutralize the solution with $N H_4 H O$, and boil until colorless. Add 5 c. c. H Cl, and pass $H_2 S$ through the boiling solution until the precipitate of S, &c., agglomerates. Filter on

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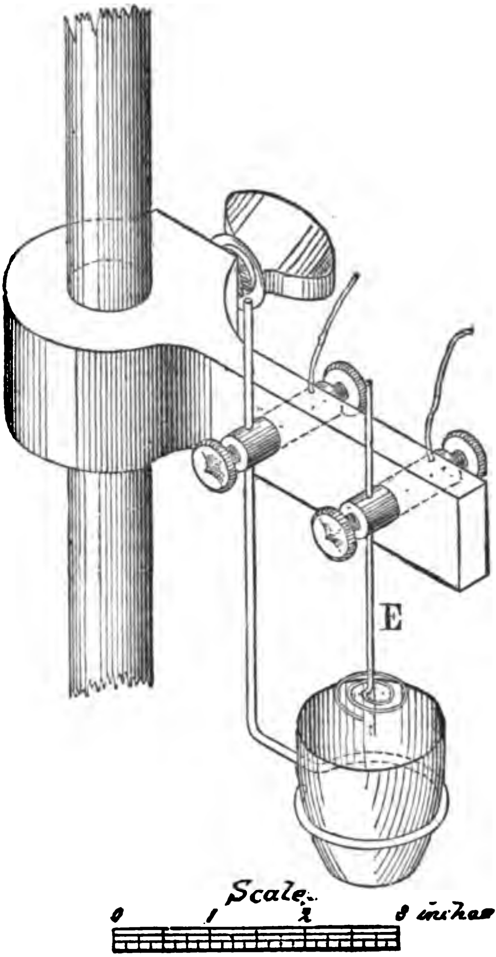
[*] To test the solubility of the ammonium-magnesium-phosphate in the solution containing citric acid, ferric oxide, ammonium chloride, &c., I made a number of experiments in the following way: The filtrate from the first precipitation of the ammonium-magnesium-phosphate was evaporated to dryness in a large platinum capsule, and heated over a Bunsen burner, until the volatile salts were driven off and the separated carbon partly burned away, the residue transferred to a platinum crucible, the carbon burned off, and the residue fused with a small amount of sodium carbonate. It was then boiled with water, and the soluble sodium carbonate and phosphate separated by filtration. To the clear filtrate a slight excess of hydrochloric acid was added, and the solution boiled, a single drop of solution of ferric chloride added, and the ferric oxide and phosphate precipitated by ammonia and excess of acetic acid; the precipitate filtered, washed, redissolved in hydrochloric acid, and any phosphoric acid present precipitated as ammonium-magnesium-phosphate.

The results of these experiments, between twenty and thirty in number, and on samples containing from .015 per cent. to .314 per cent. phosphorus, showed that when the amount of ferric oxide thrown down was so large that it required from six to eight grammes of citric acid to keep it in solution, upon the addition of ammonia, and when the solution measured 150 c. c., about 25 c. c. being strong hydrochloric acid, the maximum amount of magnesium pyrophosphate found was 1.5 milligrammes, equivalent, when 5 grammes of steel was used, to .008 per cent. phosphorus. When the amount of ferric oxide precipitated was kept within proper bounds (requiring from two to three grammes of citric acid to keep it in solution), and when the bulk of the solution was only from 20 to 50 c. c., an unweighable trace only in a few cases and usually no ammonium-magnesium-phosphate was found.

[†] In the case of pig-irons it is better to evaporate the solution to dryness, for otherwise the gelatinous silica is liable to clog the filter.



a ribbed filter, wash with boiling water, and dry the filter and precipitate. Ignite carefully in a porcelain crucible, and when the filter is perfectly burned allow it to cool and digest at a gentle heat, in $H N O_3$, with a few drops of $H_2 S O_4$, covering the crucible with a watch-glass. When the Cu S is perfectly decomposed, remove the watch-glass, and evaporate off the $H N O_3$ until fumes of $S O_3$ appear. Cool, dilute a little, and wash out carefully into a small platinum crucible. Place the crucible in the apparatus shown in cut. Lower the small platinum spiral E until it is just clear of the bottom of the crucible, and attach two cells to the battery. In from 3 to 4 hours add the third cell (see article on Cu in ingot copper), and allow to run an hour; then wash out the crucible (testing the solution by $H_2 S$ or $K_4 Fe_2 Cy_6$), first with water and then alcohol; dry at about 100 C. for a few minutes, cool and weigh. If the precipitate is dark colored,* it may be dissolved in a few drops of $H N O_3$ diluted, and the Bu reprecipitated as before, when it will always be perfectly bright and metallic in appearance. Dissolve out the Cu with a little $H N O_3$, wash out the crucible with water and alcohol, dry and weigh, the difference being copper. The extreme delicacy and accuracy of this method are beyond all praise; $\frac{1}{10}$ mg. can be detected and estimated. This amount gives a decided metallic stain on the crucible, and the most delicate tests fail to show any Cu in the liquid after precipitation by the battery, as above.

MANGANESE, NICKEL, AND COBALT.

Weigh out 3 grammes of borings into a beaker of at least 1000 c. c. capacity, and dissolve in $H N O_3$, adding H Cl if necessary. When solution is complete, evaporate to dryness, and add 20 c. c. H Cl, evaporate to dryness, and heat until all acid is expelled, redissolve in 15 c. c.

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* This dark color is of no importance, for I have frequently redissolved and reprecipitated Cu having this appearance, and have never found a greater difference than $\frac{1}{10}$ of a mg., the second precipitate being perfectly bright and metallic.

H Cl, and heat on sand-bath about 30 minutes. Dilute to almost 400 c. c. with cold water, and add solution of $Na_2\ C\ O_3$ with constant stirring until after standing some time a decided precipitate remains. Redissolve this precipitate with the smallest possible amount of dilute H Cl, added drop by drop, with constant stirring, and add 7 grammes sodium acetate, dilute with hot water to about 800 c. c., and heat to boiling. Boil about $\frac{1}{2}$ to $\frac{3}{4}$ of an hour, nearly fill the beaker with boiling water, and allow to stand on water-bath until precipitate of oxide and basic acetate of iron has settled to small bulk. Decant off clear supernatant fluid, refill the beaker with boiling water, adding a little sodium acetate, stir well, and allow to settle as before. Repeat the decantation, refilling as before, and after the third decantation dissolve the precipitate in the beaker in H Cl and a little $K\ Cl\ O_8$, evaporate off the excess of acid, and reprecipitate the iron as before.

Wash several times by decantation as at first, evaporate the decanted liquid to small bulk, and finally throw the precipitate on a large-ribbed filter, allowing the liquid to run into the beaker containing the decantations, and wash the precipitate once or twice with hot water. The solution will contain more or less oxide of iron decanted off with the supernatant fluid, so that after evaporating down to 75 or 100 c. c. in bulk, filter on a small filter into a No. 3 beaker, wash once or twice, and stand the solution aside. Dissolve the precipitate on the filter in H Cl, allowing the solution to run back into the first beaker, evaporate off excess of acid, dilute to 50 c. c. with cold water, neutralize by $Na_2\ C\ O_3$, and precipitate by sodium acetate. Boil a few minutes, and filter into the beaker containing the clear solution. Add to this solution, which should not exceed 150 c. c. in bulk, a little acetic acid, and pass a brisk stream of $H_2\ S$ into it from 30 to 45 minutes, keeping the solution at a boil. Filter and wash with $H_2\ S$ water containing a little free acetic acid. The precipitate which contains the Cu Ni and Co as sulphides should be dried and ignited in a porcelain crucible. Transfer the ignited precipitate to a No. 1 beaker, and dissolve it in H Cl and a few drops of $H\ N\ O_3$, evaporate to dryness, redissolve in 10 or 12 drops of H Cl, dilute, boil, and precipitate the copper by $H_2\ S$, filter, wash with hot water, and evaporate the filtrate to dryness. Redissolve in 4 or 5 drops of H Cl, dilute with one or two c. c. of water, and add excess of solution of potassium nitrite slightly acidulated by acetic acid. Stir and allow to stand for 24 hours, with occasional stirring. Filter off the double nitrite of cobalt and potassium, and wash with water containing potassium acetate and a little free acetic acid. Reserve the filtrate, and wash the precipitate, and filter free from potassium acetate with alcohol. Ignite the filter and precipitate, carefully, in a porcelain crucible, being careful not to raise the temperature so high as to fuse the precipitate; transfer to a very small beaker, and digest in H Cl and a little $K\ Cl\ O_3$. Evaporate to dryness, redissolve in from 3 to 4 drops of H Cl, dilute with cold water, add excess of sodium acetate, and boil from 1 to 2 hours to precipitate the small amount of $Fe_2\ O_3$ and $Al_2\ O_8$ that is always present. Filter, to the filtrate add excess of $N\ H_4\ H\ O$ and $N\ H_4\ H\ S$, and heat to boiling. As soon as the precipitate of Co S has settled, filter, wash with water containing a little $N\ H_4\ H\ S$, dry and ignite the precipitate in a platinum crucible. When thoroughly ignited, allow to cool and digest in the crucible with $H\ N\ O_3$, evaporate to dryness, and add a few drops of strong $H_2\ S\ O_4$, digest until the sulphide and oxide are changed to sulphate of cobalt, drive off excess of $H_2\ So_4$, and finally heat to a dull red for a few moments, cool and weigh as $Co\ S\ O_4$, which contains 37.98 per cent. of cobalt. Heat the filtrate from the potassium cobalt double nitrite to boiling, and precipitate the $Ni\,O$ by a very slight excess of $K\,H\,O$. Filter and wash with hot water. Dissolve the precipitate on the filter with $H\,Cl$, allow the solution to run back into the same beaker, and wash the filter well with hot water. Evaporate the filtrate to dryness, redissolve in from 3 to 4 drops $H\,Cl$, dilute with cold water, add excess of $Na\,C_2\,H_3\,O_2$, boil from 1 to 2 hours, filter off the $Fe_2\,O_3$ and $Al_2\,O_3$, heat the filtrate to boiling, and precipitate the $Ni\,S$ by $H_2\,S$, or by adding an excess of $N\,H_4\,H\,S$ slightly acidulating with $C_2\,H_4\,O_2$, and passing $H_2\,S$ through the boiling solution until the mixed S and $Ni\,S$ agglomerate. Filter, wash with $H_2\,S$ water, dry and ignite the precipitate. When perfectly burned, allow the crucible to cool, and add a little ammonium carbonate; heat carefully to dull red, cool and weigh as $Ni_2\,S$ or $Ni\,O$, which contains 78.59 per cent. nickel. If the precipitate of $Co\,S$ is very small, it may be ignited in the same manner as the $Ni\,S$, and weighed as $Co_2\,S$ or $Co\,O$, which contains 78.61 per cent. cobalt.

To the filtrate from the precipitated sulphides of copper, nickel, and cobalt, which contains all the manganese, add $N\,H_4\,H\,O$ and $N\,H_4\,H\,S$, and allow to stand from 12 to 24 hours.* Filter, wash the manganese sulphide with water containing $N\,H_4\,H\,S$, dissolve it on the filter in hot dilute $H\,Cl$, and allow the solution to run back into the same beaker. Wash the filter well with hot water, evaporate the solution to dryness, redissolve in dilute $H\,Cl$, filter, add excess of $N\,H_4\,H\,O$, heat to boiling, and boil until all smell of $N\,H_4\,H\,O$ has disappeared. Filter off any ferric oxide, dissolve back into the same beaker with $H\,Cl$, reprecipitate, boil and filter as before. Add the two filtrates together, boil, and precipitate by solution of sodio-ammonic-orthophosphate, and slight excess of $N\,H_4\,H\,O$. Boil until precipitate becomes crystalline, filter, wash with hot water, dry, ignite, and weigh as $Mn_2\,P_2\,O_7$, which contains 38.73 per cent. of manganese. Copper cannot be estimated in this portion, as a part of it always remains with the oxide of iron precipitate, as basic acetate of copper.

CHROMIUM AND ALUMINIUM.

Weigh 5 grammes of borings or drillings into a flask of about one-half litre capacity, and pour in 20 c. c. strong $H\,Cl$, diluted with three or four times its bulk of water. Close the flask with a rubber stopper having a short piece of glass tubing run through the center, extending from the small end of the stopper toone inch beyond the large end. One end of a piece of heavy rubber tubing 2 inches long, with a horizontal slit in the middle of one side, $\frac{1}{2}$ inch long, extends over the glass tube for a distance of $\frac{1}{2}$ inch. The other end of the rubber tube is closed with a piece of glass rod. This simple valve allows the escape of gas from the flask, but prevents access of air, so that the iron is all dissolved as ferrous, the chromium as chromous, and the aluminium as aluminium chloride. Assist the action of the dilute acid by heat if necessary, and when the iron or steel is entirely dissolved remove the valve, drop in a small lump of $Na_2\,Co_3$, and close the flask with a solid stopper. Cool the flask and contents as quickly as possible, and when cold dilute the solution with cold water until the flask is three-fourths full. Add with constant agitation a slight excess of $Ba\,C\,O_3$.† Shake the flask thoroughly several times, loosening the stopper to allow the CO_2 to escape; cork the flask tightly, and allow it to stand over night. Filter as rapidly as possible, rinse out the flask several times, and wash the precipitate well with cold water. The precipitate consists of the residue from the steel or iron insoluble in dilute HCl, all the Cr as Cr_2O_3, all the Al as Al_2O_3, some Fe_2O_3, and the excess of $BaCO_3$ added to the solution. Dissolve the precipitate on the filter in dilute HCl, clean out the flask with the same reagent, and allow the solution to run into a small clean beaker. Wash the filter with hot water, allowing it to run into the same beaker. Boil the solution, and add a slight excess of dilute H_2SO_4; allow to settle, and filter off the precipitated $BaSO_4$. Evaporate the filtrate to dryness to get rid of the excess of acid, redissolve in the smallest possible amount of dilute HCl, dilute, add sufficient tartaric acid to hold the iron in solution when the liquid is rendered alkaline, and add excess of NH_4HO. Heat to boiling, and add NH_4HS in excess; allow the precipitated FeS to settle, filter, wash with water containing NH_4HS, and evaporate the filtrate to dryness in a platinum capsule or large crucible. Heat the residue until the ammonium salts are volatilized and the $C_4H_6O_6$ decomposed. Burn off the separated carbon, and fuse the residue with 6 parts Na_2CO_3 and 1 part KNO_3. Dissolve out in water, transfer to a beaker, add a rather large amount of $KClO_3$, rinse out crucible with HCl, add it to the solution, and then add a slight excess of HCl. Evaporate to syrupy consistency on the water-bath, adding a little $KClO_3$ from time to time to decompose the excess of HCl. Redissolve in water, add an excess of $(NH_4)_2CO_3$ to precipitate the Al_2O_3, and boil off all smell of ammonia. Filter, wash with hot water, add to filtrate an excess of HCl, and after the greater part of the $KClO_3$ is decomposed, a little alcohol, and evaporate the dryness. Redissolve in HCl, dilute, filter from SiO_2, boil the filtrate, and add an excess of NH_4HO to precipitate the Cr_2O_3. Filter, wash with the usual precautions, dry, ignite, and weigh as Cr_2O_3, which contains 68.53 per cent. of chromium. The Al_2O_3 obtained on precipitating with $(NH_4)_2CO_3$, is usually contaminated by small amounts of SiO_2 and CaO (from the $C_4H_6O_6$). To separate these impurities, dissolve on the filter in HCl, and allow to run into a small beaker, evaporate to dryness to render SiO_2 insoluble, dissolve in HCl, dilute, filter, and precipitate the Al_2O_3 by NH_4HO, being careful to boil off all smell of NH_4HO. Filter, wash well with hot water, dry, ignite, and weigh as Al_2O_3, which contains 53.31 per cent. of aluminium.

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*Bromine may be used to precipitate the manganese in the filtrate from the sulphides of nickel, cobalt, and copper, by adding it directly to this solution, and heating until the excess of bromine is volatilized and the solution becomes colorless. Filter, wash very slightly with hot water, and proceed as with the precipitate by $N\,H_4\,H\,S$.

†The $Ba\,C\,O_3$ should be perfectly pure, the presence of even a small amount of $Ba\,S\,O_4$ interfering with the end reaction. I prepare my own by dissolving $Ba\,Cl_2$ in water, filtering, adding large excess of $N\,H_4\,H\,O$, and passing $C\,O_2$ into the solution until all the Ba is precipitated as $Ba\,C\,O_3$, washing free from chlorides, drying, and grinding in water to the consistency of cream.

To determine chromium alone, dissolve the iron, precipitate by $BaCO_3$, filter, and wash the precipitate exactly as before. Then punch the filter, and wash the precipitate into a small clean beaker. Clean the flask and filter with hot dilute HCl, and wash them thoroughly with hot water, allowing all the rinsings and washings to run into the beaker.* Add enough HCl to dissolve the soluble part of the precipitate; dilute, boil, and precipitate the Cr_2O_3 and Fe_2O_3 with NH_4HO. Boil off all smell of ammonia, allow to settle, filter and wash well with hot water to get rid of all $BaCl_2$. Dry and transfer the precipitate to a platinum crucible, carefully separating it from the filter, ignite the filter, and add the ashes to the precipitate in the crucible. Before heating the precipitate, add to it in the crucible 3 grammes Na_2CO_3 and $\frac{1}{2}$ gramme KNO_3, and mix thoroughly. Heat gradually to fusion, and finally raise the heat until all the $K\,N\,O_3$ is decomposed. Cool, and treat the fused mass with hot water; filter from $Fe_2\,O_3$, wash well with hot water, acidulate the filtrate with $H\,Cl$, and evaporate to dryness with a little alcohol. Redissolve in $H\,Cl$, dilute, filter from silica, and in the filtrate precipitate the $Cr_2\,O_3$ by $N\,H_4\,H\,O$. Filter, wash with the usual precautions, dry, ignite, and weigh as $Cr_2\,O_3$, which contains 68.53 per cent. chromium.

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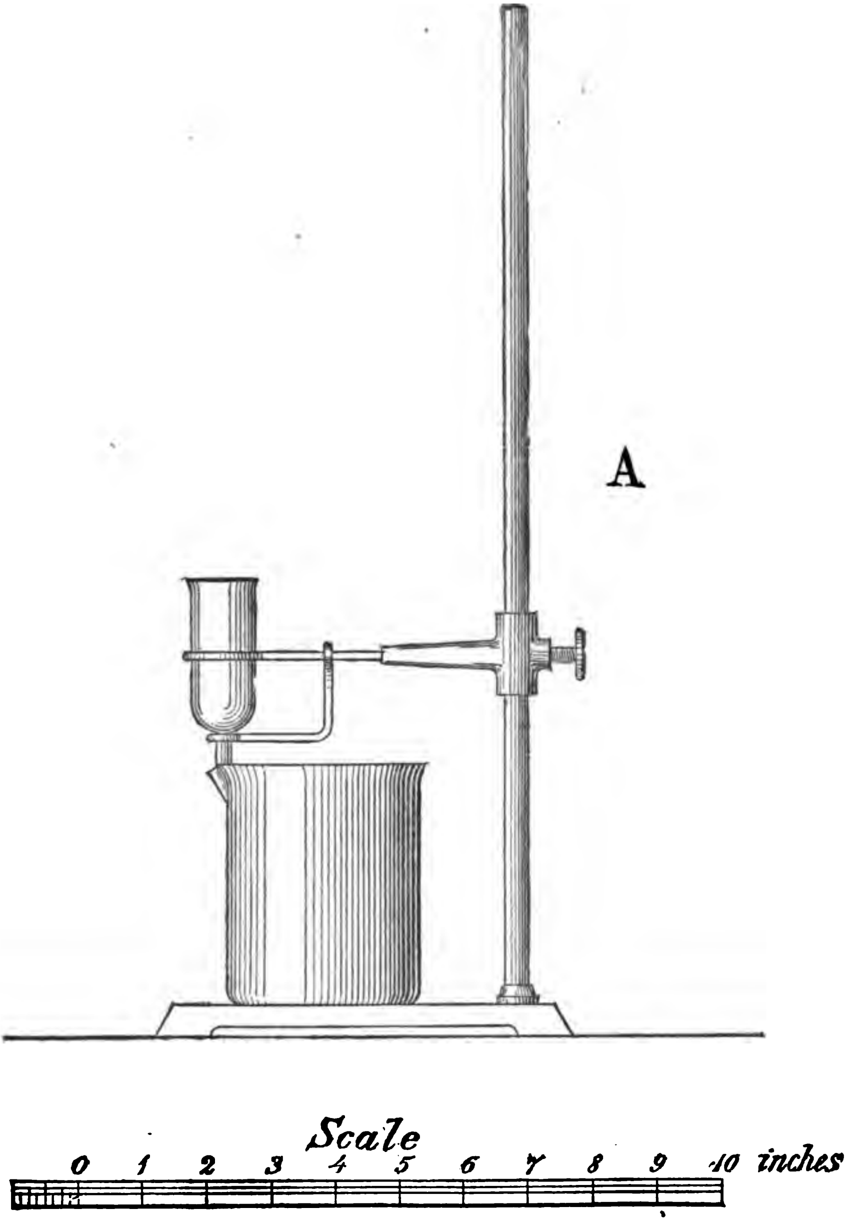
* If it is desired to determine the chromium soluble in dilute HCl alone, or separately from that which remains in the insoluble residue, the filter should not be punched, but the soluble part of the precipitate dissolved on the filter in hot dilute HCl, and a separate determination made of the Cr in the insoluble residue (which remains on the filter) by burning the filter and fusing with Na_2CO_3 and KNO_3.

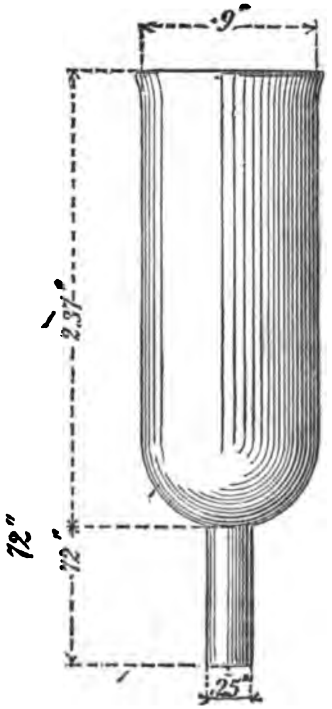


Filtering tube and stand used in carbon determinations.

TOTAL CARBON.

The selection of a method for the estimation of total carbon in iron and steel was rather a difficult problem to solve. The Eggertz color-test not being sufficiently accurate for the purposes of the Board, especially as there was so wide variation in the composition of their samples, there remained only methods more or less difficult and tedious. Many of these, while theoretically perfect, were so difficult to execute practically, that it seemed worth while to devote a little time to the investigation of various methods, with the hope of finding one capable of meeting the requirements of the Board. These requirements are: extreme accuracy, reasonable speed, and no undue difficulty of manipulation.

The method finally adopted, and which I believe fully meets these requirements, is as follows: Weigh out 3 grms. of borings or drillings, which need not be very fine, but which if possible should contain no large lumps, into a No. 3 Griffin's beaker, and add 200 c. c. of a saturated neutral solution of the double chloride of copper and ammonium.*



B

After it has stood at the ordinary temperature for 15 minutes with constant stirring, it may be placed on the water-bath, and stirred occasionally until the copper first precipitated is dissolved in the excess of double chloride used. When the copper is almost or entirely dissolved, redissolve by means of a few drops of H Cl any basic salt of iron that has separated out, allow the carbon to settle, and filter on an asbestos filter. This filter is made by placing a small plug of asbestos loosely in the filtering-tube shown in Fig. B. This plug should not be more than ¼ inch thick, and is made by picking apart asbestos which has been digested in H Cl, washed thoroughly with water, and ignited in a tube in a current of air or oxygen at a high temperature. The fiber should not be long, as the carbon may pass through the plug; neither should it be very short, as in this case the plug will not hold together well, and the solution will pass through too slowly. After transferring the carbon to the tube, clean the beaker from any adhering basic salt with an acid solution of the double chloride, and remove any carbon that remains with a little asbestos in a pair of platinum-pointed forceps, and wash the filter with warm water until it is free from chlorides. Open out the boat (Fig. D), and transfer the asbestos and carbon while wet to it, wiping out the tube with asbestos held in the forceps. Bend the boat back to its proper shape, and dry in an air bath at

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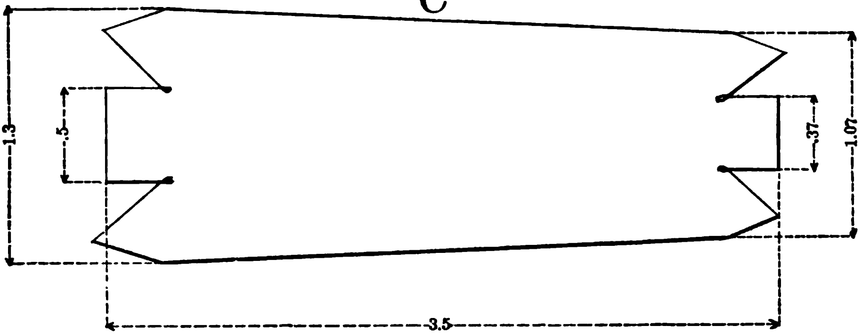
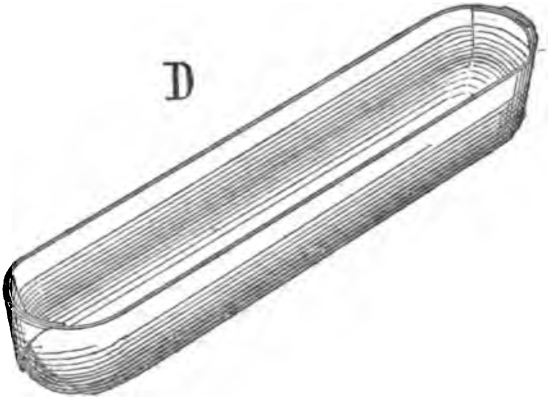
* This salt was first used by Mr. A. S. McCreath, chemist to the second geological survey of Pennsylvania, and is made by dissolving together chloride of ammonium and neutral chloride of copper in their atomic proportions, and crystallizing out the double salt. This is purified by solution and recrystallization, then dissolved in the smallest possible amount of distilled water, filtered through asbestos into a clean bottle, and dilute NH_4HO added until a slight permanent precipitate of cupric hydrate is formed. It is then ready for use.

100° C. The boat is made of platinum foil, cut in the shape shown in Fig. C, and bent in the form shown in Fig. D. Platinum is a better material for the boat than copper, as it lasts for an indefinite number of determinations; and as, unlike copper, it does not absorb oxygen, there is no danger during the combustion that a rapid absorption will cause a reflux of the caustic potassa solution in the Liebig bulb. This is very liable to occur when copper is used, unless the operation is watched most carefully, and the current of oxygen regulated. Insert the boat in the tube B, shown in the plate, and burn the carbon in a stream of oxygen.

C



D



The apparatus consists of a ten-burner gas-combustion furnace, A (see plate), 13 inches long, through which runs the porcelain tube B.* This tube is 25 inches long, and ¾ of an inch in internal diameter. It projects 6 inches outside the furnace at each end, and the heat is prevented from reaching the ends of the tube by the sheet-iron screens L. The tube is filled for a length of 6 inches, or from the middle of the tube to the front end of the furnace, with coarse oxide of copper or loosely fitting coil of coarse copper gauze thoroughly oxidized. The latter is readily fitted for use by inserting it in its proper place in the tube and heating it for several hours in a stream of oxygen. A roll of thin sheet silver 3 or 4 inches long, and wide enough to make a roll completely filling the tube, is placed just in front of the oxide-of-copper plug, and serves to hold any chlorine which may be liberated during the combustion. The tube is fitted at the forward end with a U tube, G, filled with Ca Cl_2, to which is attached another U tube, H, filled with pumice saturated with a solution of $Cu\,S\,O_4$, and heated until the $Cu\,S\,O_4$ becomes anhydrous. To this tube is attached the Liebig bulb I, filled with a solution of potassium hydrate (sp. gr. 1.27), and the drying-tube J, filled partly with pieces of K H O and partly with $Ca\,Cl_2$. I and J constitute the apparatus for absorbing the $C\,O_2$, and to the end of J is fitted a small tube, K, filled with $Ca\,Cl_2$ or K H O, to prevent the absorption by J of moisture from the air during the progress of the combustion. By cutting the pasteboard box in which the Liebig bulb usually comes, as shown in the plate, a very convenient holder for the absorption apparatus may be made. When not attached to the combustion tube, the apparatus is always fitted with little rubber caps. They serve to prevent gain and loss of moisture by the drying tube and potash bulb respectively, and are made by cutting a piece of soft black rubber tubing, and squeezing one end until it is permanently closed by adhesion of the cut surfaces. The necessity for their use is shown by the following experiments:

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*Instead of a porcelain tube I now use one made of platinum, 18 inches long and ⅝ inch internal diameter, drawn out at the forward end to ¼ inch diameter for an additional 6 inches. It has a ground joint at the rear end, the full size of the tube. The forward end of the tube is filled for a distance of 6 inches with a roll of fine platinum gauze. The U tube G is filled, half with pumice saturated with Cu S O_4, and half with fine copper turnings, separated from the pumice by a plug of asbestos. The U tube H contains Ca Cl_2.

Change of weight of absorption apparatus in very dry winter weather, balance-room heated by furnace without water pan, potash bulb and drying tube open on balance for 15 hours, —0.0004 grm.; + 0.0009 grm.; for three days, —0.0014 grm. In very damp summer weather, 15 hours, + 0.0017 grm.; + 0.0040 grm.; for three days, + 0.0150 grm. In very damp summer weather, the drying tube alone open on balance, in 15 hours, gained 0.0053 grm.; in the same time the potash bulb lost 0.0004 grm. These are only a few of a large number of experiments, all showing that in dry weather the gain by the drying-tube nearly counterbalances the loss by the potash bulbs, while in damp weather the gain by the former is always largely in excess of the loss by the latter. With the rubber tips there is no appreciable change of weight in any weather, even after a lapse of several days. The necessity for the use of the safety drying-tube K is shown by the following experiments:

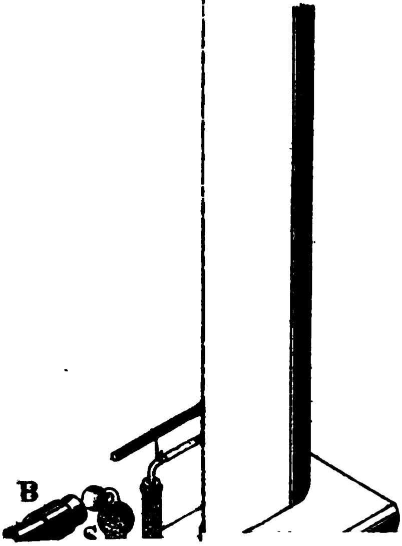
The combustion was made in the usual manner, except that the porcelain tube was empty; consequently there should be neither loss nor gain in the weight of absorption apparatus. In very dry winter weather, without safety-tube, the rooms being heated by perfectly dry hot air, the weight of absorption apparatus changed + 0.0006 grm.; — 0.0001 grm.; no change. In damp summer weather, + 0.0038 grm.; + 0.0022 grm.; + 0.0032 grm.; + 0.0035 grm. With the safety-tube K, the change is not appreciable.

As will be seen by the plate, the connections between the oxygen-holder O and the purifying apparatus M, the air bottles F, &c., are all of glass. I found by a large number of experiments that rubber tubing when used for those connections gave off some slight amount of hydrocarbon gas, which increased the weight of the absorption apparatus in blank combustions from 0.0017 grm. to 0.0035 grm.

The combustion is conducted in the following manner: Wipe off the absorption apparatus and place it on the balance. After it has been there long enough to have perfectly acquired the temperature inside the balance-case (about 30 minutes), remove the tips to equalize the pressure of the air inside and outside the absorption apparatus. Allow to stand from 10 to 15 minutes, and weigh. Insert the boat in the tube B, pushing it up against the end of the oxide-of-copper plug with the rod C. Close the tube tightly with the cork R, attach the absorption apparatus, test to see that it is all air-tight, open the pinch-cock P, and close Q. Start a slow stream of oxygen through the apparatus. Heat the tube B carefully, beginning at the forward end, so as to heat the oxide-of-copper plug well before the boat is heated. When all the burners are lighted,

Plate IV.

ERMINA



which takes generally from 35 to 45 minutes, allow them to burn turned on full for 25 minutes, the tube being at a full red all the time. Close the valve of the oxygen-holder, put on the pinch-cock P, take off Q, and start a slow stream of air through the apparatus to drive out the oxygen. This is done by pouring water into the upper bottle F, and allowing it to run into the lower one, thus forcing the air through the apparatus. When the lower bottle is full, siphon the water out. In this way the bottles need never be shifted.

Lower the lights together very gradually to avoid cracking the tube, and finally put them out. Run one liter of air through, then stop the current, detach the absorption apparatus, draw out the boat with the rod C, and the apparatus is ready for another combustion. Weigh the absorption apparatus with same precautions used in the first weighing. The difference in weight is $C O_2$, which contains 27.27 per cent. of carbon. As may be seen by Figs. 2 and 3, one end of the boat is lower than the other. This is to allow the rod C to pass over the end of the boat, the point of the rod being horizontal. By turning the point downward it will catch inside the boat, and the boat can readily be withdrawn. The furnace, as shown in the plate, is inside a hood, to avoid heating the room too much when it is in use. I is a hole in the glass through which to pass the rod C in moving the boat in and out of the tube B. E is another hole in the glass, to allow the passage of the connecting-tube T.

By having two sets of absorption apparatus, so that one may be weighed while the other is in use, five or six combustions can be readily made in a day. If care be used in heating and cooling the tube B, one tube will last for a large number of combustions. I have made 150 combustions with one, and it is still serviceable. If platinum boats can be used, the combustion requires very little attention, and interferes but little with other work in a laboratory.*

The results obtained are very accurate. In fact, in duplicate determinations the maximum difference is 0.01 per cent. Of a number of experiments made, the following will serve to illustrate several points in the details. The results here given are only a few of the many obtained. The others are equally satisfactory, but are not given because it seems hardly necessary to multiply examples.

The same sample was treated by the double chloride of copper and ammonium, in one case in an ice-cold solution, the temperature being maintained at 0° C. during the entire operation of the solution of the iron, precipitation and subsequent solution of the copper. In the other case the operation was conducted exactly as directed above, warming the solution on water-bath, &c. The solution should not be heated above 50° C.

	Cold solution, per cent. carbon.	Warm solution, per cent. carbon.
Sample No. 1	1.154	1.156
Sample No. 2	1.156	1,153
Sample No. 3	0.252	0.246
Sample No. 4	0.343	0.345
Sample No. 5	1.100	1.102
Sample No. 6	0.484	0.489

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* The cost of the apparatus is very little. Including the furnace, which alone costs $25, the entire cost (not counting the hood, which is not a part of the apparatus, nor the oxygen-holder, which can be hired) would not exceed $35.

Comparison of results obtained by different methods on the same sample of steel.

Method used.	Per cent. carbon obtained.
Double chloride of copper and ammonium as solvent:	
Combustion of residue in boat in tube	1.156
Combustion of residue in boat in tube	1.154
Sulphate of copper as solvent:	
Precipitated copper and carbon burned in tube	1.100
Steel burned direct in boat in tube:	
Finely powdered	1.140
Coarse powder	0.944
Still coarser powder	0.822
Woehler's modification of Berzelius chlorine process	1.100

(In the above determination the Cl was not perfectly deprived of air, and the result is consequently low.)

Carbonaceous residue from solution of steel in double chloride of copper and ammonium weighed on counterpoised filter, and 70 per cent. of weight taken	1.155
Ditto	1.150

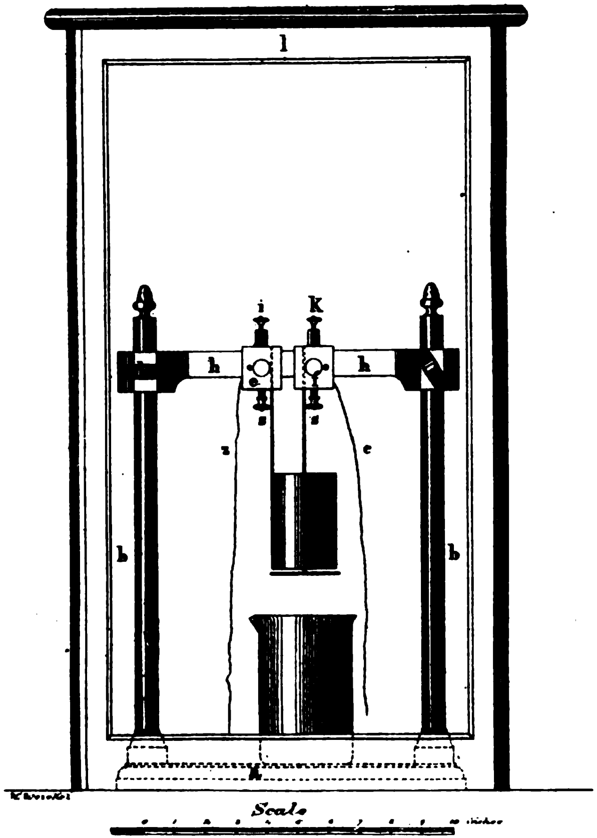
SLAG AND OXIDE OF IRON.

Weigh 5 grms. of borings free from lumps into a No. 2 Griffin's beaker. Stand the beaker, carefully covered wih a watch-glass, in a dish filled with scraped ice or snow, so that the bottom, and sides half-way up, shall be in contact with it. Pour over the iron in the beaker 25 c. c. ice-cold, boiled water, and stir until all the air in the borings has escaped. Add gradually 28 to 30 grms. of resublimed iodine, stirring occasionally until all the iodine has dissolved. Keep the beaker constantly surrounded by ice, and add the iodine slowly enough to prevent any rise in the temperature of the solution. Allow the solution to stand several hours, with occasional stirring, and when the iron is perfectly dissolved dilute with 75–100 c. c. cold boiled water, allow the insoluble matter to settle, and decant the supernatant fluid on a small filter. Wash the insoluble matter several times by decantation with cold water. Then pour on the insoluble matter a little water with a few drops of H Cl, and observe whether any hydrogen is disengaged. If none can be perceived, the metallic iron may be considered entirely dissolved; but if gas is given off, the opposite is the case. In either event, quickly decant the acidulated water on the filter, and if any metallic iron remains add a little water and some iodine to dissolve the iron entirely. When the iron is perfectly dissolved transfer the insoluble matter, consisting of graphite, carbonaceous matter, slag, oxide of iron, and some silica, to the filter, wash the filter once with very dilute H Cl (1 acid to 20 water), and finally with cold water until the filtrate is free from iron. Punch the filter, and wash the insoluble matter through into a small platinum or silver capsule. Burn the filter and add the ashes to the material in the capsule. Evaporate almost to dryness, to get rid of the water used in washing the insoluble matter into the capsule; add 50 c. c. solution of potassium hydrate, sp. gr. 1.1. Boil 15 or 20 minutes, decant the liquid on a very small close filter, repeat the boiling with fresh potassium hydrate, and finally transfer the insoluble matter to the filter, and wash with hot water until the filtrate leaves no residue on evaporating a few drops to dryness. Dry, ignite, and weigh as slag and oxide of iron.

Plate VIII

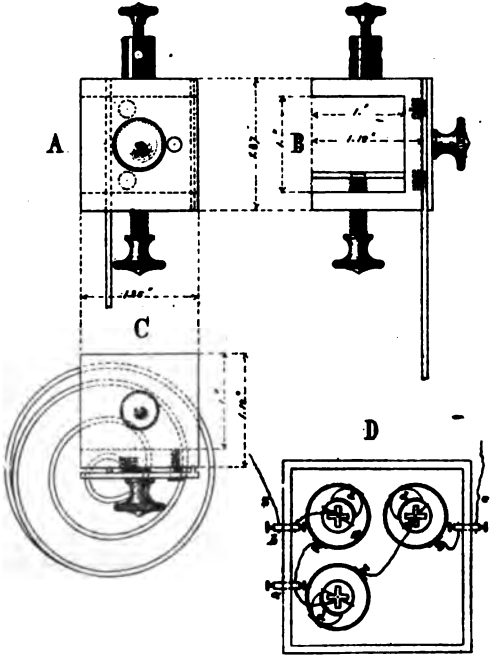
APPARATUS FOR DETERMINATION OF COPPER BY ELECTROLYSIS.

Fig. 1.



A B & C *Clamp.*

D *Arrangement of jars in battery for changing strength of currents*



COPPER AND THE ALLOYS OF COPPER, ZINC, AND TIN.

METHODS USED IN THE ANALYSIS OF INGOT AND SHEET COPPER, AND IN THE ALLOYS OF COPPER, TIN, AND ZINC.

Ingot copper usually contains, besides copper in the metallic state, copper as suboxide, silver, iron, arsenic, antimony, bismuth, lead, zinc, sometimes tin and carbon, and rarely sulphur.

For the determination of total copper, weigh out one gramme of turnings or chippings, and dissolve in 10 c. c. $H N O_3$ in a No. 3 Griffin's beaker. When solution is complete, add 6 c. c. strong $H_2 S O_4$, and evaporate down on sand bath until copious fumes of $S O_3$ are given off. Cool, dilute with cold water until beaker is three-fourths full, and determine the copper by electrolysis with the apparatus shown in Plate VIII, Fig. 1. The apparatus consists of the stand *a*, the uprights *b*, and the horizontal piece *h*, which moves on the uprights, and is secured in place by the screws *d*. The clamps *e* and *f* (three views of which are shown, A, B, and C, Plate VIII), carrying respectively the platinum cylinder and spiral (Luckow's), are secured the proper distance apart on the horizontal arm by the set-screws *s*. The two insulated wires *z* and *c* lead respectively from the zinc and copper elements of the battery, and are secured by the binding screws *j* and *k*. The whole is covered with the glass case *l* to keep off dust, &c.

Considerable difficulty was experienced in getting the proper strength of current for depositing the copper. A weak current causes loss of time by the slow deposition of the Cu, and fails to separate the last traces, even after several days. The Cu is deposited by a weak current as a beautiful metallic coating, which adheres very strongly to the cylinder. With a strong current the Cu is deposited quickly and entirely, but in a dark, spongy mass that does not adhere strongly enough to the cylinder to permit of its being washed and weighed. To avoid this, the battery is arranged as in D, Plate VIII, so that by simply changing the *z* wire from the connector *a* to *b*, the current is increased by bringing the third cell into the circuit. The box containing the battery is placed under the table on which the apparatus stands, and is covered to prevent evaporation from the battery jars. The battery consists of three Daniell's 2-quart cells, charged as follows: The cups *d* are filled with crystals of copper sulphate, the porous cells and zincs and copper-plate placed in position, the porous cells nearly filled with water containing a few drops of strong $H_2 S O_4$, and the glass jars filled to the same height with a strong solution of sulphate of copper. The connections are arranged as shown in Fig. D, Plate VIII, and the box covered. The analytical process is as follows: The *z* wire being in *a*, Fig. D, the cylinder and spiral washed and dried and placed in position, and the beaker containing the solution placed as in Fig. 1, Plate VIII, lower the horizontal arm *h* until the spiral just touches the bottom of the beaker, and allow it to remain over night. In the morning, wash down the top of cylinder and beaker, bring the third cell into the circuit by changing the *z* wire to *b*, and allow it to run two hours. Then open the clamp *f* and raise the horizontal bar *h*, leaving the spiral in the beaker, until the cylinder is clear of the beaker. Detach the cylinder, wash it with cold water and then with alcohol, dry at 100° C., and weigh. Dissolve off the Cu with $H N O_3$, wash the cylinder with water and alcohol, dry as before, and weigh; the difference is total Cu in the sample. Test the solution left in the beaker with $H_2 S$, and if any Cu S is precipitated filter it off on a small filter, and treat as in the determination of Cu in iron and steel. Add this result to the other for total copper.

SILVER.

Dissolve 10 grms. of turnings in $H N O_3$, dilute the solution, filter if necessary, and add a few drops of H Cl. Allow it to stand until the Ag Cl has settled, filter, wash, dissolve the Ag Cl on the filter in $N H_4 H O$, and allow it to run into a very small beaker. Wash well, and pour on a little $H N O_3$ to dissolve any metallic silver formed by the decomposition of the altered chloride by $N H_4 H O$, wash into the same beaker, add excess of $H N O_3$, allow the Ag Cl to settle, filter, wash, ignite, and weigh, with the usual precautions. The Ag Cl obtained contains 75.26 per cent of silver.

IRON, ZINC, NICKEL, AND COBALT.

Dissolve 10 grms. of the copper in $H N O_3$, dilute and precipitate the Cu by the battery. Remove the cylinder, wash it off into the beaker containing the solution, with cold water, evaporate the solution to dryness, add H Cl, dilute, precipitate any Cu that may remain by $H_2 S$, filter and evaporate to dryness again with a little $K Cl O_3$. Redissolve in a little H Cl, dilute, add excess of sodium acetate, boil, and filter off the iron, redissolve in H Cl, reprecipitate the oxide of iron with $N H_4 H O$, filter, burn, and weigh as $Fe_2 O_3$, which contains 70 per cent. of Fe.

Add the two filtrates together, add an excess of acetic acid, heat to boiling, and precipitate the Zn, Ni, and Co as sulphides by $H_2 S$. Filter, wash, dry, and ignite the precipitate in a small porcelain crucible. Transfer to a small beaker, and digest in aqua regia, evaporate to dryness with H Cl in excess until all $H N O_3$ is expelled, redissolve in 3 or 4 drops of H Cl, dilute a little, add excess of potassium cyanide, and precipitate the Zn as sulphide by sodium sulphide. Filter, wash, dry, and ignite the sulphide of zinc in a porcelain crucible, digest in H Cl, filter, evaporate off excess of H Cl, and precipitate the zinc by $Na_2 C O_3$. Filter, wash, dry, and ignite as Zn O, which contains 80.24 per cent. of Zn.

To the filtrate from the sulphide of zinc add excess of H Cl, and $K Cl O_3$, and boil off all hydrocyanic acid, precipitate Ni O and Co O by solution of K H O, filter, dissolve in H Cl, and separate the Ni and Co as in the determination of nickel and cobalt in iron and steel.

ARSENIC AND ANTIMONY.

(Abel & Field, Journal of Chem. Soc., XIV, 291.)

Dissolve 10 grms. of the copper in $H N O_3$, add a small amount of solution of lead nitrate, equal to 0.5 grm. of the salt, then an excess of ammonia and carbonate of ammonia. Allow the precipitate, which may contain oxide and carbonate of lead, arseniate and antimoniate of lead, and oxide of bismuth, to settle; filter, wash, and digest it in a strong solution of oxalic acid, which dissolves the arsenic and antimony. Filter, add solution of sulphate of magnesia and excess of ammonia, and precipitate the arsenic as ammonium magnesium-arseniate. Allow to settle, filter on counterpoised filters, dry at 100° C., and weigh as $2\ [As\ Mg\ (N H_4)\ O_4] + H_2 O$, which contains 39.47 per cent. of arsenic.

To the filtrate add slight excess of H Cl, and precipitate the antimony by $H_2 S$; filter, wash, and determine as $Sb_2 O_4$ by treatment with $H N O_3$. This contains 79.22 per cent. of antimony.

BISMUTH AND LEAD.

(Abel & Field, Journal Chem. Soc., XIV, 294.)

Dissolve 10 or 20 grms. of the copper in $H\,N\,O_3$, and add a small quantity of solution of sodium-ammonium-phosphate and excess of $N\,H_4\,H\,O$. Allow the precipitate to settle, filter, wash with dilute solution of ammonia, dissolve in $H\,Cl$, add excess of $N\,H_4\,H\,O$, and pass $H_2\,S$ through the solution. Filter off the precipitated sulphides of lead and bismuth, wash thoroughly, and dissolve in dilute $H\,N\,O_3$. Nearly neutralize this solution with $N\,H_4\,H\,O$, and digest with a small excess of hydrated oxide or basic nitrate of copper to precipitate the bismuth; the lead remains in solution. Dissolve the washed precipitate of oxide of bismuth in $H\,N\,O_3$, and separate it from copper by $N\,H_4\,H\,O$; filter, wash, and determine the $Bi\,O_3$ in the usual way. It contains 89.65 per cent. of bismuth.

If the copper contains iron, ferric oxide will be precipitated with the $Bi\,O_3$. In this case dissolve the precipitate in dilute acid, and precipitate by $H_2\,S$. Filter off the sulphide of bismuth, wash with water containing $H_2\,S$, redissolve in dilute $H\,N\,O_3$, and reprecipitate by ammonium carbonate; filter, wash, ignite, and weigh as before.

To the solution containing the nitrates of copper and lead add $Na_2\,C\,O_3$ until the solution is slightly alkaline, acidulate with acetic acid, and precipitate the lead as chromate by acid potassium chromate. Filter on counterpoised filter, and weigh as $Pb\,Cr\,O_4$, which contains 64.04 per cent. of lead.

CUPROUS OXIDE, OR OXYGEN.

(Abel, Journal of Chem. Soc., XVII, 164.)

Carefully weigh a piece of the copper, after cleaning the surface from any adhering oxide by means of a file or sandpaper, and digest it in a cold neutral solution of silver nitrate for three or four hours. Remove the portion unacted upon, wash it off carefully, dry, and weigh it; the difference between this and the first weight gives the amount of copper acted upon by the silver nitrate.

Filter through asbestos, and wash the mixture of precipitated silver and basic cupric nitrate. Digest it for half an hour in a known quantity of sulphuric acid containing 1 part $H_2\,S\,O_4$ to 100 parts water. Filter from the metallic silver, and determine the free acid by alkalimetry.

The quantity of acid neutralized by the cupric oxide is equivalent to the cuprous oxide, or oxygen in the metallic copper in accordance with the reaction.

$$Cu_2\,O + 2\,Ag\,N\,O_3 = 2\,Ag + Cu\,(N\,O_3)_2\,Cu\,O.$$

Professor Abel used in his estimations a solution of $Na_2\,C\,O_3$ to neutralize the sulphuric acid, but I find a solution of ammonia much more satisfactory. I have prepared the sulphuric acid and ammonia as follows:

Heat pure sulphate of copper in a porcelain crucible until it becomes anhydrous (the heat should not exceed a very low red). Transfer it to a carefully weighed glass tube, stopped with a cork covered with tin foil, while still hot; cool in a desiccator, and weigh. The difference is the weight of the $Cu\,S\,O_4$.

Wash the tube out carefully into a flask, dissolve in distilled water, heat to boiling, and precipitate the Cu by a current of $H_2\,S$. When the

Cu is all precipitated, filter, wash with hot water, and make up the filtrate to the proper volume, according to the proportion

$$159.2 : 98 = \text{wt. of } Cu\,SO_4 : \text{wt. of } H_2\,SO_4$$

so that the solution shall contain in 100 c. c. one grm. of $H_2\,SO_4$. Thirty grammes of the crystallized sulphate of copper will make about 1 liter of the standard acid.

To prepare the ammonia, take 25 c. c. strong NH_4HO, and dilute it to about 800 c. c. with distilled water. Add a few drops of an aqueous solution of haematoxylin to 25 c. c. of the standard acid diluted to about 300 c. c., and add the ammonia from a burette until the proper reaction is obtained. Then by a simple proportion determine the amount of dilution required to make 1 c. c. of the ammonia equal to 1 c. c. of the acid. For instance, if the ammonia solution, after filling the burette, measures 800 c. c., and there is required of it 20 c. c. to saturate 25 c. c. of the acid, then $20 : 25 = 800 : 1000$, and 200 c. c. of distilled water must be added to the ammonia solution to make it the proper strength.

If the ammonia solution should prove to be two weak at first, add a little strong ammonia, and repeat the titration. If upon testing the ammonia solution after dilution it should prove to be within two or three tenths of a c. c. in 50 of the proper strength, it is accurate enough.

In the determination of the suboxide of copper, after digesting the silver and basic cupric nitrate in 50 c. c. of the standard acid, and filtering from the precipitated silver, dilute to about 400 c. c., add the haematoxylin, and run in the ammonia solution from a burette until the yellow color of the solution disappears. Subtract the number of c. c. thus obtained from the number required to neutralize the standard acid; the difference is the volume of standard acid required to neutralize the basic cupric salt. Then, as 1 c. c. of the standard acid is equal to 0.01 grm. of the $H_2\,SO_4$, multiply the number of c. c. obtained by .01, and the result is the weight of $H_2\,SO_4$ neutralized. Then,

$$H_2\,SO_4 : Cu_2O = \text{wt. of } H_2\,SO_4 \text{ obtained} : \text{wt. of } Cu_2O \text{ required.}$$

Or,

$$H_2\,SO_4 : O = \text{wt. of } H_2\,SO_4 \text{ obtained} : \text{wt. of O required.}$$

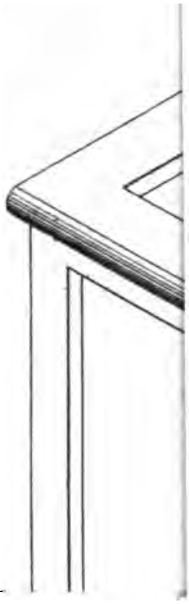
These weights divided by the amount of copper acted upon by the solution of $Ag\,NO_3$ give the percentages respectively of Cu_2O and oxygen in the copper.

TIN.

Dissolve 10 grms. of the copper in HNO_3, evaporate to dryness, and heat in a porcelain dish until the cupric nitrate is decomposed. Redissolve in HNO_3, dilute, and stand aside until the $Sn\,O_2$ shall have settled. Filter, wash, and dry the precipitate. Separate the $Sn\,O_2$ as perfectly as possible from the filter, burn the filter, and fuse the whole with equal parts of $Na_2\,CO_3$ and S. Dissolve in water, filter, and precipitate the sulphide of tin with dilute $H\,Cl$ or $H_2\,SO_4$. Filter, wash with water containing ammonium acetate, dry, and roast at a low heat until the S is burned off; raise the heat gradually, and ignite at a high temperature; finally allow it to cool and heat several times with ammonium carbonate, and until the weight is constant. Weigh as $Sn\,O_2$, which contains 78.38 per cent of tin.

If the copper contains antimony, this precipitate must be treated by Rose's method (fusion with sodium hydrate in a silver crucible), and the amount of Sb determined and subtracted from the weight of $Sn\,O_2$.

APPARA



CARBON.

Dissolve a weighed amount of the copper in double chloride of copper and ammonium, filter on asbestos, and ignite in a current of oxygen, as in determination of total carbon in steel.

SULPHUR.

Ignite the finely divided copper for several hours in a current of purified hydrogen, pass the gas through a solution of oxide of lead in potassium hydrate, and treat the precipitate as in determination of sulphur in iron and steel.

SEPARATION OF TIN AND COPPER IN ALLOYS.

Dissolve 1 grm. of the alloy in $H N O_3$, evaporate to dryness on the water-bath, cool and moisten the dry residue with H Cl. Allow it to stand at the ordinary temperature for several hours, and add about 700 or 800 c. c. of cold water. It should dissolve without residue. Add 50 c. c. of dilute H_2, $S O_4$ (one of acid to ten of water), and stand over night on the water-bath. Decant the clear supernatant fluid through a filter, wash several times by decantation with hot water, and boil the precipitate with a mixture of $H N O_3$ and water, one to ten. Allow the precipitate to settle, decant, and wash by decantation through the same filter. Finally, transfer to the filter, wash with hot water, dry, ignite, and weigh as $Sn O_2$, which contains 78.38 per cent. Sn. Test the precipitate for lead and copper by fusion with Na_2, $C O_3$, and S. Evaporate all the filtrates from the $Sn O_2$, and heat until fumes of $S O_3$ are given off. Cool, dilute, and precipitate the Cu by electrolysis, as in the determination of Cu in ingot copper.

SEPARATION OF COPPER AND ZINC IN ALLOYS.

Dissolve 1 grm. of the alloy in 10 c. c. $H N O_3$, add 8 c. c. strong H_2 $S O_4$, and heat until fumes of $S O_3$ are given off. Cool, dilute, and precipitate the Cu by electrolysis, washing off the cylinder with distilled water into the beaker containing the solution. Pass $H_2 S$ into this solution, collect any Cu S that may be precipitated on a small filter, and determine the amount as in the determination of Cu in iron and steel. To the filtrate add a little bromine water to destroy the S and oxidize any iron which may be present; neutralize with $Na_2 C O_3$, add excess of acetic acid and sodium acetate, and boil to separate the iron; filter, heat to boiling, and precipitate the zinc as sulphide by a current of $H_2 S$. Allow the precipitate to settle; wash by decantation with water containing $H_2 S$. Finally transfer to the filter, wash, dry, ignite several times with ammonium carbonate, and weigh as Zn O, which contains 80.24 per cent. of Zn.

SEPARATION OF COPPER, TIN, AND ZINC IN ALLOYS.

Digest 1 grm. of the triple alloy in $H N O_3$, evaporate to dryness, cool, moisten with H Cl, and determine the $Sn O_2$ as in the determination of Sn in copper-tin alloys. Determine the Cu in the filtrate by electrolysis as in the same separation, and the Zn in the solution from the copper precipitation, as in the determination of Zn in copper-zinc alloys.

DETERMINATION OF SMALL AMOUNTS OF LEAD IN COMMERCIAL ZINC AND ALLOYS.

I have applied Abel and Field's method for the determination of lead in ingot copper to its determination in commercial zinc (spelter) and the various alloys of Cu, Zn, and Sn. The mode of procedure is the same, except in alloys containing tin. In these treat 10 grms. of the alloy with $H\,N\,O_3$, evaporate to dryness, boil with 100 c. c $H\,N\,O_3$, and water, equal parts, dilute, filter from $Sn\,O_2$, add a little $N\,H_4$, Na, H, $P\,O_4$, and excess of $N\,H_4\,H\,O$. Allow the precipitate to settle, filter, wash with water containing $N\,H_4\,H\,O$, dissolve on the filter in hot dilute H Cl, and allow the solution to run into a small beaker. Add excess of $N\,H_4\,H\,O$ and $N\,H_4\,H\,S$. Allow the precipitate to settle, filter, and wash with water containing $N\,H_4\,H\,S$. Dry and ignite the precipitate and filter, transfer to a small beaker, digest in $H\,N\,O_3$ and a little $H_2\,S\,O_4$, evaporate off the $H\,N\,O_3$, dilute with water and alcohol, equal parts, and allow the $Pb\,S\,O_4$ to settle. Filter, wash, dry, ignite, and weigh as $Pb\,S\,O_4$, which contains 68.32 per cent. Pb.

REPORT

ON A

PRELIMINARY INVESTIGATION OF THE PROPERTIES

OF THE

COPPER-TIN ALLOYS,

MADE UNDER THE DIRECTION OF THE

COMMITTEE ON METALLIC ALLOYS,

UNITED STATES BOARD TO TEST IRON, STEEL, AND OTHER METALS,

ROBERT H. THURSTON, CHAIRMAN,

IN THE

MECHANICAL LABORATORY OF THE STEVENS INSTITUTE
OF TECHNOLOGY.

WASHINGTON:
GOVERNMENT PRINTING OFFICE.
1882.

EDITOR'S PREFACE.

The investigation of the properties of alloys of copper and tin here reported upon was entered upon under a resolution of the United States Board to Test Iron, Steel, and other Metals, passed April 17, 1875, directing a determination of "the mechanical properties and of the physical and chemical relation of alloys of copper, tin, and zinc," and under the arrangement of committees approved by the board, April 23, 1877, which assigned to the committee on alloys the duty of "assuming charge of a series of experiments on the characteristics of alloys and an investigation of the laws of combination."

This research was conducted in the Mechanical Laboratory of the Department of Engineering of the Stevens Institute of Technology under the authorization of the Trustees, who, although without power to assume responsibility involving pecuniary risk, cordially gave the work their countenance, and permitted the use of every facility which the Institute afforded in the prosecution of the work, and as have the President and members of the Faculty, aided most effectively wherever opportunity offered.

This preliminary study of a wide and important field will, it is hoped, prove to have been so satisfactorily done that a repetition of the work may never be required, and that, in the future, research may be thus profitably confined to matters of detail in those parts of this field which are here shown to be of most promise and where investigation may be most certain to yield liberal returns.

The principal assistant and observer in this extended and extremely laborious work has been Mr. William Kent, without whose intelligent assistance we should have often found it necessary to suspend work temporarily, and should have been compelled to take a very much longer time for its completion. I cannot speak too highly of his conscientious and skillful work, not only at the testing-machines, but in working up results. He is to be credited also with many valuable suggestions and with some of the very ingenious devices which have greatly abridged the work. The committee are also indebted for similar assistance to Mr. J. E. Denton, assistant in charge of the Mechanical Laboratory, to Mr. Theo. F. Koezly, and to Mr. and Mrs. F. T. Thurston. The latter were invaluable coadjutors in the preparation of the report, and especially of its illustrations. The conscientious accuracy of their work is best indicated by reference to the plates which accompany this report. Mr. F. T. Thurston is especially entitled to credit for essential assistance rendered in editing this report, every page of which has passed under his revision.

With their skillful aid, the endeavor has been made to carry out the plan of the committee faithfully and with all possible thoroughness and accuracy.

The intention of the committee was, not to determine the character of chemically pure metals, melted, cast and cooled with special precaution, but to acertain the practical value of commercial metals, as found in the markets of the United States, melted in the way that such alloys are prepared in every foundry for business purposes, and cast and otherwise treated in every respect as the brass-founder usually handles his work. The endeavor has been to determine what is the practical value, to the brass-founder and to the constructor, of commercial materials treated in the ordinary manner and without any special precaution or any peculiar treatment.

The investigation of the effect of various kinds of fluxes and methods of fluxing and of special methods of treatment of the alloys after casting, is reserved for a future research.

The result of this investigation has been the approximate determination of the mechanical properties of all alloys of copper and tin.

The set of diagrams representing the method of variation of each of these properties with variation of composition, will exhibit this result most satisfactorily.

Those diagrams form a very concise compendium of the whole work. Other diagrams are given, of which the curves exhibit the behavior of every test-piece from the instant of application of the initial load to the end of the test. The *fac similes* of the Autographic Strain Diagrams obtained automatically by the use of the Autographic Recording Testing-Machine, designed by the writer, also exhibit the characteristics of each alloy as described by itself, and give the strength, resilience, modulus of elasticity, and homogeneousness of every portion of every bar of metal made.

In the text of the report will be found a statement of the more important facts determined, and the tables appended contain all the results of observation. The whole forms a collection of facts that will probably repay a vastly more complete analysis and more careful study than it has been possible to give them.

Little more has been done than to determine facts; their comparison and the determination of laws and of corollaries is a still greater task, and months might be profitably spent in the work.

Very respectfully,

R. H. THURSTON,
Chairman of Committee,
Editor of Report.

MECHANICAL LABORATORY,
DEPARTMENT OF ENGINEERING,
STEVENS INSTITUTE OF TECHNOLOGY,
February 25, 1879.

To the United States Board appointed to test Iron, Steel, and other Metals:

GENTLEMEN: The undersigned, a committee appointed by you with instructions "to assume charge of a series of investigations of the characteristics of alloys," present herewith a report upon the Copper-Tin Alloys.

This research has been made under the direction of this committee, and under the direct supervision of its chairman. The committee will, immediately upon its completion, present a similar report upon the Copper-Zinc alloys, and a report upon the Triple Alloys of Copper, Tin, and Zinc will follow. The work has been done in the same way and under the same direct supervision as that on the copper-tin alloys.

The committee take great pleasure in presenting these reports to the board. They represent the results of the first complete and systematic researches ever made upon these most important of all the alloys of useful metals. This work has been carefully planned, and the plans formed have been completely carried out. The result has been the complete exploration of a broad and most important field of which almost nothing was previously known. Ordnance-bronze, bell metal, and speculum-metal, a few grades of brass and of the triple alloys, were the only alloys familiar to our founders and engineers.

The whole field has now been explored and the useful alloys are proven to occupy but a limited portion of its great extent, and it has been now shown that a comparatively narrow band extending from ordnance-bronze, on the one side of this triangular territory, to Muntz metal, on the other, contains all of the best of the generally useful alloys. This small portion of valuable territory having been pointed out and defined, its more minute study may be left for future investigators.

Your committee desire to invite especial attention to, and to ask a careful study of, the strain-diagrams of the copper-tin and the copper-zinc alloys, and a still more careful examination of the graphical representation of the results of the research on the copper-tin-zinc alloys, as presenting most completely and satisfactorily the characteristics of all possible combinations of the metals used.

Very respectfully,

R. H. THURSTON,
L. A. BEARDSLEE,
DAVID SMITH,
Committee on Metallic Alloys.

A PRELIMINARY EXPERIMENTAL RESEARCH UPON THE MECHANICAL PROPERTIES OF SMALL CASTINGS OF THE ALLOYS OF COPPER AND TIN.

The part of this research which has been completed, and of which the results are given in the following pages, consists of an investigation of the strength, ductility, resilience, and other mechanical properties of the alloys of copper and tin, in the form of cast bars about 28 inches long and 1 inch square in section, prepared from the best commercial metals, simply ordinary precautions being taken to secure good castings. It was desired to learn, besides the properties of each particular alloy, the laws which connected these properties with the proportions of the component metals, and also whether alloys mixed in simple proportions of the chemical equivalents of the component metals possessed any advantages over other mixtures. It was reserved for a subsequent research to determine the effect of various methods of casting, of rapid or slow cooling, of casting under pressure, of using special fluxes, and of the effects of rolling and hammering.

Two series of these alloys were made, the first consisting of twenty-nine bars, of which twenty-three were mixtures of the metals in atomic proportions, four were mixtures made without regard to the atomic proportions, and the remaining two were a bar of copper and a bar of tin, each without admixture.

The second series comprised twenty bars, ranging from 97½ per cent. copper and 2½ per cent. tin to 97½ tin and 2½ copper, with a regular difference of composition between consecutive bars of 5 per cent. In addition to these alloys a few other bars of cast copper were made and one of cast tin.

After the bars were prepared they were tested first by transverse stress in the manner hereinafter described. The pieces remaining from the transverse tests were then turned into proper shape and tested by tensile stress. The ends of the tensile-test pieces were then tested by torsion. In general, each bar sufficed for one transverse, two tensile, and four torsional tests, and in some cases compression-test pieces were made, as described hereafter. The turnings made in shaping the tensile-test specimens were carefully saved for chemical analysis. Small pieces from each tensile specimen were saved for the determination of the specific gravity.

FIRST SERIES—COPPER AND TIN ALLOYS.

The metals used in preparing the first series of copper and tin alloys were procured from responsible dealers, and reported by them to be the purest commercial metals in market. The weighing was made with great care in the Physical Laboratory of the Stevens Institute of Technology, on a balance made by Messrs. Saxton and Bache for the United States Bureau of Weights and Measures. The metal weighed out for each bar was 4.5 kilogrammes (about 9.92 pounds), and the weighing was made in all cases to within one-tenth of a gramme, the balance being sensitive to a very much smaller weight. The error in weighing was less than $\frac{1}{20000}$ of the whole.

A similar balance was exhibited by the Bureau of Weights and Measures of the United States Treasury Department at the Paris Exposition of 1867, and is stated in Prof. F. A. P. Barnard's report to have been sensitive to $\frac{1}{2000000}$ of the weight in each scale, and to have received the highest praise from eminent French authorities.*

The following table gives the composition of the alloys of the first series according to their atomic proportions and percentages of original mixture, and also according to chemical analysis made after the tests:

TABLE I.—ALLOYS OF COPPER AND TIN.—FIRST SERIES.

Composition by Original Mixture and Analysis.

Number.	Atomic proportion.		Percentage by original mixture.		Mean percentage by analysis.		Mean specific gravity.
	Cu.	Sn.	Cu.	Sn.	Cu.	Sn.	
1	1	0	100	0	....	....	8.487
2	96	1	98.1	1.9	97.89	1.90	8.564
3	48	1	96.27	3.73	96.06	3.76	8.649
4	24	1	92.80	7.20	92.11	7.80	8.694
5	....	....	90.00	10.00	90.27	9.58	8.669
6	12	1	86.57	13.43	87.15	12.73	8.681
7	....	....	80.00	20.00	80.95	18.84	8.740
8	6	1	76.32	23.68	76.64	23.24	8.565
9	....	....	70.00	30.00	69.84	29.89	8.932
10	4	1	68.25	31.75	68.58	31.26	8.938
11	....	....	65.00	35.00	65.34	34.47	8.947
12	3	1	61.71	38.29	62.31	37.35	8.970
13	12	5	56.32	43.68	56.70	43.17	8.682
14	2	1	51.80	48.20	51.62	48.09	8.560
15	12	7	47.95	52.05	47.61	52.14	8.442
16	3	2	44.63	55.37	44.52	55.28	8.312
17	4	3	41.74	58.26	42.38	57.30	8.302
18	6	5	39.20	60.80	38.37	61.32	8.182
19	1	1	34.95	65.05	34.22	65.80	8.013
20	3	4	28.72	71.28	25.85	73.80	7.948
21	3	5	24.38	75.62	23.35	76.29	7.835
22	1	2	21.18	78.82	20.25	79.63	7.770
23	1	3	15.19	84.81	15.08	84.62	7.657
24	1	4	11.84	88.16	11.49	88.47	7.552
25	1	5	9.70	90.30	8.57	91.39	7.487
26	1	12	4.29	95.71	3.72	96.31	7.360
27	1	48	1.11	98.89	0.74	99.02	7.305
28	1	96	0.557	99.443	0.32	99.46	7.299
29	0	1	0	100	....	....	7.293

Analyses of the ingot metal used in these alloys were made, with the following results:

	Ingot Lake Superior Copper.	Ingot Banca Tin.	Ingot Queensland Tin.
Metallic iron	0.013	0.035	0.035
Metallic zinc	none	none	none
Metallic silver	0.014	......	......
Metallic arsenic	none	none	trace
Metallic antimony	none	none	none
Metallic cobalt	......	......	none
Metallic bismuth	none	none	none
Metallic nickel	......	......	none
Metallic lead	trace	none	0.165
Metallic manganese	......	......	0.006
Metallic molybdenum	......	none	none
Metallic tungsten	......	......	none
Metallic copper	99.420	none	none
Metallic tin	none	99.978	99.794
Suboxide of copper	0.537	......	......
Carbon	0.041	......	......
Matter insoluble in aqua regia	......	trace	......
	100.025	100.013	100.00

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*United States Reports on Paris Exposition, Vol. III, p. 485.

All the bars were made in the brass foundry of the Mechanical Laboratory of the Stevens Insitute of Technology, by an experienced brass founder, but considerable difficulty was met with in the cases of many of them in consequence of the variable and unusual proportions in mixtures adopted which necessitated different methods of treatment. Several bars had to be recast one or more times to secure even fairly good castings.

The crucibles used were made of a composition of plumbago and fire-clay. They were 6½ inches in height and 4¼ inches largest diameter, inside measurements. The furnace was an ordinary brass founder's furnace, furnished with a strong chimney draught. The fuel used was anthracite coal. In mixing, the copper was first melted and the tin added in the solid state, in small portions at a time, and the mixture thoroughly stirred with a dry wooden lath.

The first castings were made in dry sand molds, but so much trouble was given by irregular surfaces and blow-holes that recourse was had to a cast-iron mold, which gave better results. When the metal was poured at too low a temperature into the cold mold it was sometimes slightly chilled, giving an irregular surface. This was remedied by heating the mold to a temperature somewhat below the melting point of the alloy, the highest temperature being given it in casting alloys containing the largest percentages of copper. In all cases the mold was placed in a vertical position while the metal was being poured and cooled. The following is a statement of the method of casting of each of the twenty-nine bars.

No. 1. All copper. Cast twice in dry sand mold. Bar broke in middle each time (probably by shrinkage). Cast in cold iron mold—surface uneven. Cast in hot iron mold—good.

No. 2. 97.89 copper, 1.90 tin. Cast in dry sand—good.

No. 3. 96.06 copper, 3.76 tin. Cast in cold iron mold—spongy appearance on surface. Recast in hot iron mold—surface somewhat streaked and irregular.

No. 4. 92.11 copper, 7.80 tin. In cold iron mold—surface bad. Recast in hot iron mold—good.

No. 5. 90.27 copper, 9.58 tin. In hot iron mold—good.

No. 6. 87.15 copper, 12.73 tin. In dry sand—good.

No. 7. 80.95 copper, 18.84 tin. In dry sand—bad surface. Recast in hot iron mold—good.

No. 8. 76.64 copper, 23.24 tin. In dry sand—good.

No. 9. 69.84 copper, 29.89 tin. In dry sand—good. Very weak and brittle, and broke in handling. Recast in hot iron mold—good.

No. 10. 68.58 copper, 31.26 tin. In hot iron mold—good.

No. 11. 65.34 copper, 34.47 tin. In hot iron mold—good.

No. 12. 62.31 copper, 37.35 tin. In hot iron mold—good. Broke in taking out of mold. Recast three times before getting a good casting.

No. 13. 56.70 copper, 43.17 tin. In hot iron mold—good. Broke in handling. Recast twice, breaking each time in the mold. Fourth casting good.

No. 14. 51.62 copper, 48.09 tin. In hot iron mold—good. Broke in handling, leaving piece 19 inches long sufficient for test.

No. 15. 47.61 copper, 52.14 tin; to No. 23. 15.08 copper, 84.62 tin, inclusive. In hot iron molds—first castings good.

No. 24. 11.49 copper, 88.47 tin. In hot iron mold. Bottom of mold not well stoppered, and part of metal ran out. Recast—good.

No. 25. 8.57 copper, 91.39 tin. In hot iron mold. Ran out of bottom of mold. Recast—good.

No. 26. 3.72 copper, 96.31 tin. In hot iron mold—good.
No. 27. 0.74 copper, 99.02 tin. In hot iron mold—good.
No. 28. 0.32 copper, 99.46 tin. In hot iron mold—good.
No. 29. All tin. In cold iron mold—surface irregular. Recast in cold iron mold with like result. In hot iron mold broke, apparently by shrinkage. Recast several times in hot mold before getting a good bar.

After casting, the bars were finished to a rectangular section by chipping and filing, and the more brittle bars by grinding with an emery-wheel.

EXTERNAL APPEARANCE OF THE BARS.

Much could be learned from the appearance of the bars after casting, both of their properties and of their probable behavior under test. The following were characteristic features:

(1) A regular gradation in color took place from bar No. 1, all copper, down to No. 8, 76.64 copper, 23.24 tin, the polished surface of which latter was light golden yellow. There was a regular gradation in hardness, the No. 8 being filed with great difficulty.

(2) A sudden change of color and of all properties took place at bar No. 9—69.84 copper, 29.89 tin. This bar was silver-white in color, and so hard that it could not be touched with a file. Pieces broken off showed a smooth, curved or conchoidal fracture. No. 10—68.58 copper, 31.26 tin—was almost exactly similar to No. 9, and No. 11—65.34 copper, 34.47 tin—but little different.

(3) Another change of color and properties at No. 12—62.31 copper, 37.35 tin—which bar was of a dark bluish-gray color, and the fracture somewhat similar to that of a piece of granite or other hard rock. This was the most dense alloy of the series, as shown in the table of specific gravities. No. 13—56.70 copper, 43.17 tin—was similar to No. 12, but lighter in color and a little softer.

(4) Bar No. 14—51.62 copper, 48.09 tin—was peculiar in showing a marked difference of color and of other properties in the two ends of the bar. The upper end was precisely like bar No. 12, while the bottom was of a much lighter color, granular fracture, and was so soft that it could be cut with a knife like a piece of chalk or soapstone.

(5) A change of properties between bars No. 14 and No. 20—25.85 copper, 73.80 tin—occurred gradually, the bars becoming whiter and softer, and the appearance of fracture changing from rough and stony-like to crystalline or granular. No. 20 could be cut with a knife, giving a short chip which had slight cohesion. From No. 20 to No. 29 (all tin) the softness increased gradually, No. 21 giving a malleable chip on being cut. From No. 24 to No. 29 the appearance of all the bars was very much the same, differing slightly in hardness, and scarcely at all in color.

From these appearances it would have at once been conjectured that bars No. 1 to No. 8 were the only ones likely to prove of value where strength was required, and that bars No. 9 to No. 18, inclusive, were deficient in ductility as well as in strength, and for all practical purposes (except, perhaps, the extremely limited use for special purposes, as speculum metal) absolutely worthless.

Nearly all of the bars appeared to be good castings, except the following: No. 1, all copper, had several blow-holes in the upper surface, chiefly at the upper end; No. 2—97.89 copper, 1.90 tin—had a large cavity in the bottom end of the bar, about 2 inches long and varying from ¼ to ½ inch in diameter; No. 21—23.35 copper, 76.29 tin—had a blow-hole or cavity extending the whole length of the bar, except 5 inches of the upper end. Its diameter was afterward found to vary from ⅛ inch to nearly ½ inch in different parts of the bar. This was a peculiar case, and nothing resembling it was met with in bars of different compositions.

TRANSVERSE TESTS.

Tests of the first series by transverse stress were made with dead weights on an apparatus built for the purpose, a sketch of which is shown below.

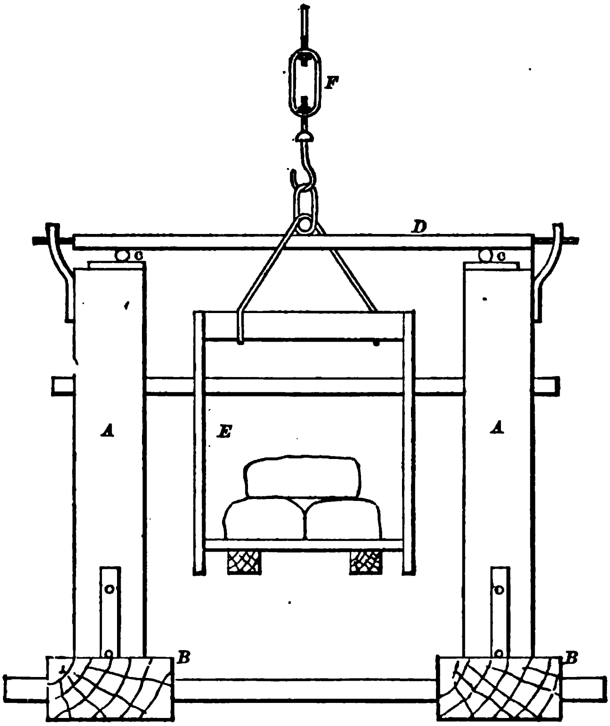

Fig. 1.

A A are two vertical pieces of timber firmly braced to base pieces B B. Two flat steel plates are fastened on the top of the vertical timbers and their upper surfaces made perfectly level. Two steel mandrels, *c c*, 1¼ inches in diameter, rest on these plates and support the bar to be tested, D. The weights are placed on the tray E, which hangs from a third mandrel resting on the upper edge of the bar at its center. The tray, with the weights and mandrel, may all be raised at once by a differential pulley. In lowering, the pulley is used till the mandrel nearly touches the bar, when the turnbuckle F is employed to complete the operation gradually and without shock.

In testing the bars by means of this apparatus, fine lines were scored on each bar to indicate the position of the center and of the points of support. The latter were 22 inches apart and equidistant from the center. The mandrels, *c c*, were then placed on the flat steel plates, and held at the distance of 22 inches apart between centers, by calipers made for the purpose, and the bar placed on the mandrels, with the lines marked for the points of support directly above the centers of the mandrels. The tray and its attachments weighing 35 pounds, all weights less than this in amount were hung directly on the center of the bar by means of a hook bearing on its upper surface. When the tray was used it was lowered very gradually by means of the differential pulley and the turnbuckle, and additional weights placed on the bottom of the tray, care being taken to keep the center of gravity of tray and weights always as nearly as possible directly under the center of the bar.

The deflections and sets produced by the applied loads were measured by means of a Salleron's cathetometer, which gave readings to $\frac{1}{50}$th of a millimeter, or $\frac{1}{1270}$th of an inch. This instrument is shown in the accompanying cut.

The observations were made by noting through the telescope a fine dot made on a piece of white paper glued to the center of the bar. The cross-hairs of the telescope were caused to bisect this dot, and the error of observation was not larger than one division of the vernier.

The tables of results seem to indicate that the sum of all errors of observation and of the instrument might sometimes reach as high as $\frac{1}{10}$th of a millimeter when reading sets, but was always less than this when reading deflections.

While raising and lowering the weights to take readings of sets, the bar was prevented from rolling on the mandrels by two small pins, which were held by brackets on the upright timbers of the apparatus, and just brought in contact with each end of the bar. The slightest change of position could at once be detected by the observer at the telescope of the cathetometer.

Complete tables of the results of these tests are appended. A condensed summary of results is given below. In these appended tables are given the results of every test that was made. In tables giving summaries and averages of results, and in curves and in deductions made from them, all tests which are considered unsatisfactory by reason of imperfections in the piece tested or other causes are rejected, and only those tests which were made with sound test specimens are retained.

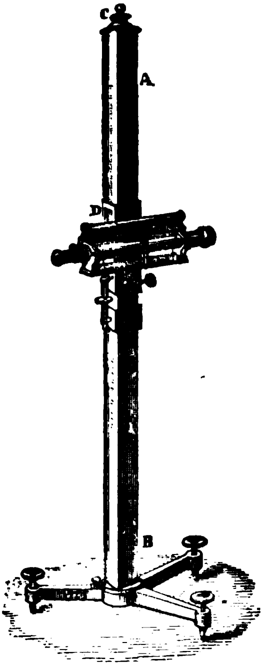

Fig. 2.

TABLE II.—*First Series Alloys of Copper and Tin.*

Tests by Transverse Stress.

No.	Mean composition by analysis.		Length between supports.	Breadth.	Depth.	Breaking-load.	Modulus of rupture.	Total deflection.	Limit of elasticity.		First set of 0.01 inch.		Modulus of elasticity. $E=\frac{l^3}{4\Delta bd^3}(P+4)$		
	Copper.	Tin.	l	b	d	P	$R=\frac{3}{2}\frac{l}{bd^2}(P+8)$	Δ	Load. P_1	Corresponding value of $R_1=\frac{l}{bd^2}(P_1+3)$	Load. P_2	Corresponding value of $R_2=\frac{l}{bd^2}(P_2+3)$	P	Δ	E
			Inches.	*Inches.*	*Inches.*	*Pounds.*		*Inches.*	*Lbs.*		*Lbs.*		*Pounds.*	*Inches.*	
1	Cast copper	....	22	0.994	1.010	650	21,251	2.306	225	7,420	250	8,284	200	0.038	13,986,605
2	97.89	1.90	22	1.011	1.005	550	......	4.561 +	175	5,753	200	6,561	175	0.041	11,324,079
3	96.06	3.76	22	1.000	0.998	1,000	33,232	7.634 +	350	11,696	400	13,352	350	0.069	13,739,654
4	92.11	7.80	22	0.997	1.012	1,350	43,731	6.706 +	575	18,682	600	19,450	450	0.082	14,263,420
5	90.27	9.58	22	1.008	0.933	1,485	49,400	7.534 +	600	20,019	600	20,019	500—100	0.077	14,012,135
6	87.15	12.73	22	0.996	1.003	1,050	34,531	2.291 +	300	9,936	400	13,216	200	0.051	10,532,146
7	80.95	18.84	22	0.908	1.011	1,750	56,715	0.492	1,150	37,308	900	29,215	1,100—100	0.194	13,304,198
8	76.63	23.24	22	0.998	1.002	975	32,210	0.191	975	32,210	975	32,210	950—100	0.167	13,495,122
9	69.84	29.88	22	0.992	1 000	360	12,076	0.062	360	12,076	360	12,076	350	0.062	15,321,736
10	68.58	31.26	22	0.990	1.004	275	9,152	0.043	275	9,192	275	9,192	250	0.043	15,694,556
11	65.63	34.47	22	0.982	1.003	140	4,776	0.020	140	4,776	140	4,776	140	0.020	19,344,368
12	62.31	37.35	22	0.992	1.000	80	2,761	0.032	80	2,761	80	2,761	30	0.0095	9,603,989
13	56.70	43.17	22	0.998	0.990	60	2,126	0.103	60	2,126	60	2,126	50	0.0103	14,693,513
14	51.62	48.09	17¼	1.005	0.992	140	3,877	0.040	140	3,877	140	3,877	60	0.018	5,171,546
15	47.61	52.14	22	0.990	1.000	105	3,600	0.019	105	3,600	105	3,600	50	0.0087	17,039,130
16	44.52	55.28	22	1.000	0.994	140	4,776	0.026	140	4,776	140	4,776	50	0.0067	16,823,869
17	42.38	57.30	22	1.002	0.991	210	7,172	0.042	210	7,172	210	7,172	140	0.017	23,238,907
18	38.37	61.32	22	0.988	1.003	250	8,400	0.060	250	8,400	250	8,400	125	0.028	12,302,353
19	34.22	65.80	22	0.991	1.004	160	5,384	0.043	160	8,414	130	4,393	100	0.025	11,041,901
20	25.85	73.80	22	0.990	1.002	240	8,067	0.121	140	4,747	120	4,083	40	0.012	9,982,832
21	23.35	76.29	22	1.002	0.995	370	12,408	0.269	140	4,471	150	4,784	40	0.0103	11,520,262
22	20.25	79.63	22	0.988	1.006	300	10,019	0.345	100	3,334	100	3,334	25	0.0095	9,743,644
23	15.08	84.62	22	1.004	0.995	270	9,063	0.858	60	2,091	50	1,759	25	0.0111	7,032,130
24	11.49	88.47	22	0.978	0.980	300	10,706	5.849	75	2,756	85	3,109	30	0.0095	10,403,101
25	8.57	91.39	22	1.002	1.006	160	5,305	8.000 +	40	1,399	60	2,050	25	0.0095	7,965,988
26	3.72	96.31	22	1.005	1.005	210	6,925	8.000 +	40	1,398	60	2,048	30	0.0103	8,613,200
27	0.74	99.02	22	1.000	1.012	120	3,964	8.318	40	1,386	50	1,708	25	0.011	6,771,517
28	0.32	99.46	22	0.989	1.000	130	4,438	8.114	40	1,435	70	2,436	40	0.0126	9,398,650
29	....	Cast tin	22	0.993	1.002	110	3,740	8.395	30	1,002	40	1,423	20	0.0095	6,734,838
30	Cast copper	....	22	0.990	0.980	860	29,848	8.000 +	120	4,254	160	5,638	30	0.0224	10,203,205

Remarks.—No. 1. Defective, full of blow-holes; fourth casting. No. 2. Defective, full of blow-holes; bent; first casting; sand mold. No. 3. Bent; second casting; iron mold. No. 4. Bent; second casting; iron mold. No. 5. Bent; first casting; iron mold. No. 6. Defective, not homogeneous; first casting; iron mold. No. 14. Short bar and much liquated. No. 17. Liquated. Nos. 26, 27, 28, 29, and 30, bent.

NOTES ON THE TESTS BY TRANSVERSE STRESS.

Bar No. 1, all copper, proving to be a bad sample of cast copper, another bar was made, No. 30, which gave much better results. The great differences in the behavior of these two bars will be referred to at some length further on.

In the appended tables, in the column headed "Load," the figures represent the weights applied to the bar.

The formula for deflection of long bars tested by transverse stress, within the elastic limit, is given by writers on resistance of materials as

$$\Delta = \frac{P\,l^3}{4\,E\,b\,d^3} + \frac{5}{8}\,W\,\frac{l^3}{4\,E\,b\,d^3},$$

where Δ is the deflection, P the applied load, W the weight of the bar between supports, E the coefficient (or, as generally termed, the modulus) of elasticity,* l, b, and d the length between supports, breadth and depth of the bar. As the weight of the bar between supports in these tests was from 6 to 7 pounds, 4 pounds may be substituted for $\frac{5}{8}$ W, and the formula becomes—

$$\Delta = \frac{l^3}{4\,E\,b\,d^3}\,(P + 4 \text{ pounds}),$$

whence—

$$E = \frac{l^3}{4\,\Delta\,b\,d^3}\,(P + 4 \text{ pounds}),$$

from which latter formula the moduli of elasticity given in the tables of tests of each bar were calculated.

It will be observed in these last tables that in many of them, especially in tests of the stronger metals, the modulus of elasticity increases slightly

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* The modulus of elasticity is a value which expresses the relation between the extension, compression, or other deformation of a bar, and the force which produces the deformation. In tensile stress it is the load per unit of sectional area divided by the extension per unit of length. In transverse tests it is obtained from the formula given above. The value of E found by tests by tensile stress is said to be the same as that obtained by transverse tests of long bars. The formula given above for deflection of bars tested by transverse stress, viz:

$$\Delta = \frac{P\,l^3}{4\,E\,b\,d^3},$$

is not quite accurate, as it neglects the deflection due to shearing stress, which varies directly as the load. The true formula (the weight of the bar itself not being considered) is—

$$\Delta = \frac{P\,l^3}{4\,E\,b\,d^3} + \frac{P\,l}{4\,E_s\,b\,d}$$

in which E_s is the coefficient of elastic resistance to shearing.

In the tests herein described, l, in general is 22 inches; b and d are each nearly one inch. The formula then reduces approximately to

$$\Delta = \frac{10648\,P}{4\,E} + \frac{22\,P}{4\,E_s}.$$

The value of E_s is shown (see Wood's "Resistance of Materials") never to be greater than $\frac{2}{5}$ E, which would make the last term of the above equation

$$\frac{2 \times 22}{5 \times 4\,E} = \frac{44}{20\,E},$$

which is only $\frac{1}{1210}$ of the first term of the second member of the equation. The resistance to shearing may therefore be neglected in calculating the modulus of elasticity from transverse tests of bars 22 inches long, as the error thereby introduced is less than one-tenth of 1 per cent. The error is much larger, however, with shorter bars.

at the beginning of the test, then remains nearly constant for a certain distance, or slowly approaches a maximum; and then at first slowly and afterward very rapidly, decreases to the breaking point. This corresponds with what is shown in the plotted curve of deflections, viz, the beginning of the curve sometimes shows a slight curvature convex to the axis of abscissas, then a straight line slightly inclined from the vertical. The inclination from the vertical then increases, at first slowly and afterward more rapidly, till the curve takes a more nearly horizontal direction.

In the table given above, the figures in the column headed "Modulus of elasticity" are those which are considered the *most probable* moduli within the elastic limit, or which most nearly represent the relation between the stresses and the distortions within that limit. In most cases the maximum modulus given in the tables of tests of each bar is selected, unless the deflection corresponding to the maximum is so small a quantity as to render the probable error of the observation a large portion of the apparent deflection.

In a few instances the apparent modulus at the beginning of the test is much smaller than it soon afterward becomes; and this indicates a possible error of the observations at this part of the test. The moduli of these bars, given in the above table, are therefore determined by rejecting the deflections at the beginning of the test, and taking the ratio of distortion to stress at a point where this ratio becomes sensibly constant.

In the column headed "Modulus of elasticity," the figures of deflections and loads corresponding to the assumed most probable moduli are given. The tests in which the first portion was rejected in obtaining the modulus are indicated in the figures of load by giving the limits between which the modulus is taken.

The modulus of rupture* is found from the formula

$$R=\frac{3}{2}\frac{l}{b\,d^2}\left(P+\frac{1}{2}W\right)$$

where P is the applied load causing fracture, W the weight of the bar between the supports, and *l*, *b*, and *d* length, breadth, and depth as before.

Substituting an approximate value for the weight of the bar we have

$$R=\frac{3}{2}\frac{l}{b\,d^2}\left(P+3\right)$$

where P is the applied load.

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* The modulus of rupture is defined by some writers as "the strain at the instant of rupture upon a unit of the section which is most remote from the neutral axis on the side which first ruptures" (Wood's Resistance of Materials, ii, edit., 1875, p. 79). It is used here as a means of comparing the transverse strength of bars of different breadths and depths, the strength of bars tested by transverse stress varying directly as the load, directly as the length, and inversely as the breadth and the square of the depth, or in cases of bars supported at both ends and loaded in the middle, as expressed by the formula

$$R=\frac{3}{2}\frac{Pl.}{b\,d^2}$$

If the dimensions are all reduced to unity, the formu[illegible] becomes

$$R=\frac{3}{2}P.$$

In other words, the modulus of rupture is a value which is proportional to the transverse strength of a bar, and is theoretically equivalent to one and a half times the load which would break a bar one unit in length, in breadth, and in depth, supported at both ends and loaded in the middle.

The more ductile bars, as seen in the tables of tests, bent without breaking. The correct modulus of rupture in these cases, therefore, could not be determined, and it was necessary to assume a given amount of bending as equivalent to breaking the bar or rendering it useless. This was taken at a deflection (while the load rested on the bar) of 3½ inches, and the modulus of rupture is calculated from the load causing this maximum deflection, as affording a means of comparing the transverse strengths of all the ductile bars which were tested.

The limit of elasticity is taken to be the point at which the deflections begin (usually suddenly) to increase in a greater ratio than the applied loads, and in the plotted curves of deflections it is the point at which the curve begins to diverge from its original and nearly vertical direction and becomes nearly horizontal.

This point is not always clearly defined, and it is difficult to fix its exact position.

The limit of elasticity coincides in some, though not in all, cases with the first observed set or point at which the bar under test exhibits a deflection after the load is removed.

The point of "first appreciable set" given in the tables is taken as a set of 0.01 inch, which is an amount much beyond the limits of error of observation.

For the purpose of comparing the resistances of the different bars to stress at the elastic limit and at the first appreciable set, with their resistances at the points of final rupture, values of

$$R_1 = \frac{3 P_1 l}{2 b d_2}$$

are taken, in which P_1 is the load corresponding to the limit of elasticity or to appreciable set.

BEHAVIOR OF THE BARS UNDER STRESS.

A glance at the table of results given above shows that from bar No. 1 (all copper) to bar No. 7—80.95 copper, 18.84 tin—inclusive, there was a gradual increase of strength, except in the cases of bars No. 2 (97.89 copper, 1.90 tin) and No. 6 (87.15 copper, 12.73 tin), which were defective. Bars No. 2 to No. 5 (1.90 tin to 9.58 tin) showed great ductility as well as strength, as deflections exceeding 4½ inches were given them without breaking. Bar No. 1 (all copper) broke after a deflection of 2.306 inches, while bar No. 30, also copper, bent (as shown in the appendix) to about 8 inches before breaking, showing a marked difference in ductility as well as in strength. This was due probably to oxidation of the copper in bar No. 1 by repeated melting and casting.

Bar No. 7 (80.95 copper, 18.84 tin), the strongest of the series, showed comparatively little ductility, breaking after a deflection of little over half an inch. From No. 8. to No. 13 (23.24 to 43.17 tin) inclusive, there is a regular and very rapid decrease both in strength and ductility, the latter being the weakest bar of the series, showing only about $\frac{1}{27}$th of the strength of No. 7 and a deflection of only 0.0103 inch. As before stated, this bar gave great trouble in casting by breaking in the mold. Bar No. 9 (69.84 copper, 29.89 tin) which, in appearance, also differed remarkably from No. 8 (76.64 copper, 23.24 tin) had less than ⅗ of its strength and less than ½ of the strength of No. 7, which latter differed only 10 per cent. from it in composition by original mixture or 11 per cent. by analysis. Bars No. 14 to No. 20 (48.09 to 73.80 tin), inclusive, show a somewhat irregular variation in strength and ductility, but all of them are worthless as regards either of these qualities, the best having only about $\frac{1}{7}$th of the strength of the maximum, and a deflection of only 0.123 inch before breaking. Bar No. 21 (23.35 copper, 76.29 tin) shows considerably greater strength and ductility than any of the series between No. 8 and No. 20, and greater strength than any from No. 8 to No. 29 (all tin), thus giving what may be called a second maximum point of strength in the series. This bar had a cavity extending throughout nearly its whole length.

No 21 to No. 24 (76.29 to 88.47 tin) have much higher strength than those above and below them in series, showing that the second maximum point of strength is approached by bars having a difference of over 10 per cent. in composition. From No. 25 to No. 29 (91.39 to 100 tin) there is a somewhat irregular decrease of strength, but a very great increase of ductility, bar No. 29 (all tin) showing the maximum ductility of the series and a second minimum of strength. Bars No. 26 to No. 29, inclusive, bent without breaking, as did those from No. 2 to No. 6 (1.90 to 12. 73 tin) at the other end of the series.

With reference to the relation of the elastic limit to the ultimate transverse resistance, it will be seen that from bars No. 1. to No. 7, inclusive, the elastic limit occurred at from 35 to 65 per cent. of the ultimate resistance. At No. 8 the limit of elasticity approached nearly if not quite the ultimate resistance; and from No. 9 to No. 18 (29.89 to 61.32 tin), inclusive, the two coincided, *i. e.*, the elastic limit was not reached till the bar broke. From No. 19 (34.22 copper, 65.80 tin) to the end of the series (all tin) the elastic limit was again reached before fracture, the ratio decreasing to No. 22 (20.25 copper, 79.63 tin), and then remaining appreciably constant at from 20 to 30 per cent. to the end of the series.

By this table, therefore, the relation which the composition bears to the mechanical properties of strength, ductility, and elastic resistance is defined with tolerable exactness.

It is seen that bars from No. 1 to No. 8, inclusive, have considerable strength, and that all the rest are practically worthless for all purposes where strength is required. The dividing line between the strong and the brittle alloys is precisely that at which the color changes from golden-yellow to silver-white, viz, at a composition containing between 24 and 30 per cent. of tin; alloys containing more than 24 per cent. tin are comparatively valueless.

Referring to Tables ——, which are appended, a short account of the behavior of each bar will now be given.

Bar No. 1 (cast copper).—Weights were applied, one pound at a time, until 7 pounds were reached (11 pounds, including the effective weight of the bar), when the first deflection was observed, 0.004 inch. The load was then increased 5 or 10 pounds at a time until 100 pounds were reached; after each increase and the reading of the corresponding deflection, the load was all removed and a reading of the set taken. After 100 pounds each increase was made 25 pounds, removing the load and reading the set each time after reading the deflection. A set of 0.0016 inch was observed when the load of 12 pounds was removed, but as readings of sets up to 225 pounds were irregular and never exceeded 0.007 inch, these readings may be erroneous, the error being due to a combination of several causes, viz, personal errors of observation of the bisection of the cross-hairs in the telescope of the dot observed by it, and of the reading of the vernier; slight lateral shifting of the bar on the rollers, and a slight compression of the skin of the bar at the points which touched the rollers. The first three errors named would not amount to more than 0.001 inch each, and might either increase or decrease the reading. The last would act only to increase the reading, and would vary in amount with the condition of the surface resting on the rollers, the rougher the surface the greater the amount of compression by the rollers. This error could be eliminated only by polishing the bars at the points which rested on the rollers and taking all precautions to insure a perfectly fair bearing. It would increase the apparent deflections by about the same quantity by which the sets were increased, and this may account for the fact that the apparent deflections at the beginning of a test often bear a greater ratio to the applied load than at a subsequent stage of the test, thus showing an apparently lower modulus of elasticity at the beginning of the test than just before reaching the elastic limit.

The sum of these errors possibly amounting to 0.007 inch, the point which has been taken as a standard of comparison of "first appreciable set" of the different bars is a set of 0.01 inch. In bar No. 1 this amount of set took place after the application and removal of the load of 250 pounds. The elastic limit is taken at 225 pounds, this being the point where the deflections evidently begin to increase in a greater ratio than the applied loads. At 450 pounds the deflection of the bar was observed to increase slightly as the load was left on for five minutes, and the same phenomenon was again observed at 600 pounds. An increase of deflection was observed on the second application of every load after 400 pounds. Except where otherwise stated, in this and in all other tests, the load was left on the bar only long enough for a reading to be taken, and the repetition of the observation to insure correctness, the time required being from one to two minutes.

After 650 pounds had been placed on the bar, and then removed and the reading of the set taken, a small crack was discovered on the under side of the bar, near the middle, and, on gradually replacing the weight of 549 pounds, the bar broke. The fracture showed the bar to be a poor one, being spongy and full of blow-holes, the largest of which was ¼ inch in diameter.*

An analysis was made of the turnings of this bar and also of bar No. 30 for the purpose of learning whether the chemical composition would throw any light upon the causes of the presence of the blow-holes and the lack of ductility of this bar as compared with that of other bars subsequently tested.

The result was the discovery of an extraordinary amount of suboxide of copper in bar No. 1. This was no doubt formed in the repeated meltings which the bar had undergone.

The following are the analyses:

	No. 1.	No. 30.
	Per cent.	*Per cent.*
Metallic iron	0.020	0.014
Metallic zinc	0.014	0.057
Metallic silver	0.035	0.014
Metallic arsenic	none	none
Metallic antimony	none	none
Metallic tin	none	......
Metallic bismuth	none	none
Metallic lead	trace	trace
Metallic copper	87.900	96.330
Suboxide of copper	12.086	3.580
Carbon	none	......
	100.055	99,995

A graphic representation of the test of this and other bars is given on Plate No. XVI. The curves graphically representing these tests exhibit the relative behavior of each bar much better than the tables.

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* See account of bar No. 30 for a test of a good bar of copper.

Bar No. 2 (97.89 copper, 1.90 tin).—This bar was tested in the same manner as No. 1 but with less frequent readings of sets, only two being made before 200 pounds was placed on the bar; these readings showed no set. At 200 pounds a set of nearly 0.01 inch was observed. The deflections begin to increase more rapidly than the loads after reaching 175 pounds, which load is taken as at the elastic limit. At 275 pounds the bar was noticed to sink slowly after the load was applied, but the load was increased without stopping. At 375 pounds the bar appeared to sink quite rapidly. At 475 500, and 550 pounds the load was left on the bar 3, 10, and 3 minutes respectively, producing a large increase of deflection each time. At 575 pounds the bar bent rapidly and slid through between the supports. As a deflection of 3½ inches was caused by the load of 550 pounds, this is considered as the breaking weight, from which the modulus of rupture is calculated.

The bar was finally broken by bending alternately in contrary directions, and the principal cause of its weakness in comparison with the copper bar was found to be its spongy structure.

A vast number of very minute blow-holes, almost microscopic in size, were found. Further tests on pieces of this bar showed this structure throughout all the upper portion of the bar, but the lower portion was much more compact. As this structure may probably be due to accidental causes, and not inseparable from its composition, the strength shown by this particular bar is thought to be beneath that which may be expected from other bars of the same composition, and hence the bar is not given in the curve showing the relation of transverse strength to composition, Plate I. The modulus of elasticity is less than that of any other bar from No. 1 to No. 6.

Bar No. 3 (96.06 copper, 3.76 tin).—This bar proved to be much stronger than either of the preceding. A set of 0.01 inch took place at 400 pounds, and the limit of elasticity is considered to have been reached at 350 pounds. At 600 pounds the bar was observed to sink while under stress, and it was left for 50 minutes, the deflection increasing during that time from 0.181 to 0.252 inch; the rate of increase of deflection gradually diminishing, the first 10 minutes showing an increase of 0.048 inch, the next 20 minutes 0.015 inch, and the next 20 minutes 0.008 inch. The same phenomenon was noticed several times during the test, the bar once being left under stress of 850 pounds for 15 hours 45 minutes, the last 15 hours of the time showing a much less increase of deflection than the first five minutes.

From the test of this bar, and others in like manner, it appears that the increase of deflection finally ceases, provided the load is not greater than a certain limit for each bar. When the load is too great a still more curious phenomenon is observed, as in the case of the bar in question, when a load of 1,000 pounds was placed on it, viz, the decrease of the rate of increase of deflection, and again after a certain time the increase of this rate till the bar finally breaks down. In this case the increase of deflection with the first five minutes was 0.422 inch, in the next five minutes 0.120 inch, showing a decreasing rate; in the next 30 minutes 0.442 inch, showing a slight increase of the rate, and in the next 30 minutes 3.532 inches, showing a very rapid increase. At this point the bar had a deflection of 7.634 inches and the tray reached the base of its supports, thus ending the test. On breaking this bar, the fracture showed a homogeneous metal free from blow-holes.

Bar No. 4 (92.11 copper, 7.80 tin).—A set of 0.01 inch was reached at 600 pounds, and the elastic limit at 575 pounds. The effect of allowing the load to remain on the bar was observed several times after 950 pounds had been reached, with similar results to those indicated when describing the behavior of bar No. 3. At 1,350 pounds the deflection increased in 30 minutes from 3.226 inches to 6.706 inches, when the bar slid through between the supports. On breaking the bar, after bending in contrary directions, the fracture showed a compact-looking metal, of an earthy appearance, with scarcely any luster, and with only a few very small blow-holes. The color was not entirely homogeneous, some parts being more grayish than others, the general color being reddish-yellow.

Bar No. 5 (90.27 copper, 9.58 tin).—A set of 0.01 inch was reached at 600 pounds, and the elastic limit at the same point. Time-tests were made after 950 pounds were applied, but in no case was a load left longer than 15 minutes. The behavior of this bar was very similar to that of bar No. 4, the deflections corresponding to the various loads being nearly the same for each bar. Its ultimate strength, however, was greater, 1,485 pounds being required to give it a deflection of 3½ inches, the same increasing the deflection in 13 minutes, to 7.534 inches, causing the tray to reach the base of its supports. In breaking the bar, it was first bent by pressure until the two ends touched, and then bent in a reverse direction, but broke before being straightened. The fracture showed a dense, compact metal, but not entirely homogeneous in color or structure. There were a few small blow-holes, and the lower part of the fracture was of a dull, earthy appearance, with portions of a fibrous appearance. The color was dull reddish-yellow, except a distinctly large spot in the center of a very dark red (darker than copper) and a few small yellow spots. This metal, although stronger than any of the bars previously tested, is probably not so strong as it might have been had it been homogeneous.

Bar No. 6 (87.15 copper, 12.73 tin).—A set of 0.01 inch was reached at 400 pounds and elastic limit at 300. A few "time-tests" were made, showing increase of deflection under constant load after 700 pounds. The bar proved to be much weaker than the two which preceded it, and broke at 1,050 pounds. The cause of the weakness was at once shown by the appearance of the fracture. Two distinct colors were seen, golden-yellow and silver-gray, finely mottled together over the whole surface of the fracture, indicating that liquation or an imperfect mixture of the two metals had taken place, and that the two colors were probably those of two distinct alloys, intimately mixed. The modulus of elasticity, as well as the limit of elasticity, and the ultimate strength of this bar are very low, and as the bar is considered a defective one, like bar No. 2 (97.89 copper, 1.90 tin), the results are omitted in constructing curves. It will be observed that the modulus of elasticity is less than that of any bar from No. 1 to No. 11 (all copper, to 65.34 copper, 34.47 tin).

Bar No. 7 (80.95 copper, 18.84 tin).—This bar proved to be the strongest of the series. A set amounting to 0.01 inch was not detected until 900 pounds had been placed on the bar, and this was increased only to 0.016 inch at 1,200 pounds. The limit of elasticity appears to be passed at 1,150 pounds. The load of 1,750 pounds was allowed to remain on the bar for 15 hours, during which time the deflection increased 0.027 inch. At the end of the 15 hours the load was removed and a reading of the set taken. The load was then replaced gradually, the last portion of the 1,750 pounds being replaced, a pound at a time. The last pound had been replaced, and the reading of the deflection was about to be made, when the bar suddenly broke at a point 2 inches from the middle. The fracture showed a close, compact structure, and a reddish or pinkish gray color, entirely different from that of any of the bars previously tested. Although this bar is the strongest of the series, it has much less power to resist sudden shocks, in consequence of its lack of ductility, the maximum deflection being only 0.537 inch.

Bar No. 8 (76.64 copper, 23.24 tin).—The behavior of this bar was similar to that of No. 7, but it was much weaker and had much less ductility, breaking with the load of 975 pounds, and showing a maximum deflection of but 0.191 inch. No set amounting to 0.01 inch was found, the greatest being 0.0055 inch at 900 pounds. The elastic limit was apparently not reached till fracture took place, the ratio of deflection to the loads remaining constant throughout the whole test. The fracture showed a metal somewhat similar to No. 7, but lighter in color.

Bar No. 9 (69.84 copper, 29.89 tin).—This bar showed great lack of both strength and ductility, breaking at 360 pounds after a deflection of 0.062 inch. As with bar No. 8, no set amounting to 0.01 inch could be detected. and the elastic limit was not reached till fracture took place. The fracture showed a metal of an entirely different character from any of those previously tested, almost as brittle as glass, with a vitreous appearance and brilliant luster, almost silver-white in color, with no indication of the presence of copper, which formed 70 per cent. of its weight. The shape of the fracture was peculiar; a side view of it is shown below:

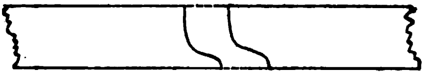

FIG. 3.

Bar No. 10 (68.58 copper, 31.26 tin).—This bar was almost precisely similar in appearance and action under test to bar No. 9, but showed a still less degree of strength and ductility, breaking at 275 pounds, after a deflection of 0.043 inch. As in the case of bar No. 9, no set of 0.01 inch and no elastic limit were reached before fracture.

Bar No. 11 (65.34 copper, 34.47 tin).—This bar exhibited still less strength and ductility than either of the preceding, breaking at 140 pounds. after a deflection of 0.02 inch, showing no set and no elastic limit before fracture. The structure as shown by the fracture was quite different from those of bars No. 8 and No. 9, being rough granular instead of vitreous. The modulus of elasticity increases from the beginning to the end of the test, reaching a much higher figure than any of the preceding bars.

Bar No. 12 (62.31 copper, 37.35 tin) was still more brittle and weaker than No. 11. It broke at 80 pounds, after a deflection of 0.032 inch. A set of 0.103 inch was observed at 70 pounds, but no limit of elasticity was detected. The fracture showed a metal of much darker color than No. 11, and of an appearance somewhat like stone. This metal had a greater specific gravity than any other in the series. Its modulus of elasticity is less than one-half of that of bar No. 11.

Bar No. 13 (56.70 copper, 43.17 tin).—The weakest and most brittle of the series, breaking at 60 pounds, after a deflection of only 0.0103 inch, with no apparent set and no elastic limit before fracture. The appearance of the fractured metal was somewhat similar to that of No. 12, but lighter in color.

Bar No. 14 (51.62 copper, 48.09 tin).—This bar was shorter than the rest of the bars of the series, its length between supports being 17¼ inches. It proved to be somewhat stronger than No. 13, breaking at 140 pounds, after a deflection of 0.040 inch. A set of 0.01 inch was observed at 65 pounds, but it had increased only to 0.019 at 130 pounds, and no elastic limit was reached before fracture. This bar showed a difference of structure and color at the two ends, due to liquation or separation of the metals into distinct alloys; the chemical analyses of samples taken from the two ends showed a difference of composition of more than 10 per cent. The modulus of elasticity is exceptionally low. This may possibly be due to errors of observation of deflection.

Bar No. 15 (47.61 copper, 52.14 tin).—Broke at 105 pounds after a deflection of 0.019 inch. No set was detected, and no limit of elasticity before fracture.

Bar No. 16 (44.52 copper, 52.28 tin).

Bar No. 17 (42.38 copper, 57.30 tin).

Bar No. 18 (38.37 copper, 61.32 tin).

These three bars were all similiar in behavior to No. 15, very weak and brittle, giving no sets amounting to 0.01 inch, and no elastic limits before fracture. No. 17 gave a modulus of elasticity much higher than any other bar of the series.

Bar No. 19 (34.22 copper, 65.80 tin).—This was similiar to the four preceding bars, but took a set of 0.0118 inch at 130 pounds. The position of the elastic limit is very doubtful, but it appears to have been passed at 100 pounds. The modulus of elasticity is less than half of that of No. 17. It appears that the modulus decreases from this bar to the end of the series, but with considerable irregularity.

Bar No 20 (25.85 copper, 73.80 tin).—Weak and brittle like No. 19, but had a slightly greater ductility, showing a deflection of 0.121 inch before breaking, and a set of 0.01 inch at 120 pounds. It broke at 240 pounds, and the elastic limit appears to have been passed at about 140 pounds. The color and appearance of the fracture were similiar to those of the five preceding bars. The modulus of elasticity is highest at the beginning of the test, and rapidly decreases from the beginning to the end. This is common to all the bars from No. 20 to No. 29 inclusive, and is characteristic of all the ductile metals which have no well defined limit of elasticity. The moduli of these bars, given in the above table of results, are in general those corresponding to deflections of 0.01 inch.

Bar No. 21 (23.35 copper, 76.29 tin).—This bar was remarkable in having a hole extending from the bottom throughout nearly its whole length. The hole varied in size and shape in different parts of the bar. At the point of fracture, it was nearly circular in section, about ¼ inch in diameter, and nearly in the center of the section. Notwithstanding the presence of this cavity, the bar proved to be stronger than any of the bars from No. 9 to No. 29. It broke at 370 pounds, after a deflection of 0.269 inch. A set of 0.01 inch was reached at 150 pounds, and the elastic limit was reached at 140 pounds. The fracture showed a light-gray, fine granular appearance, slightly darker than No. 20.

Bar No. 22 (20.25 copper, 79.63 tin).—This bar was somewhat weaker than No. 21, but more ductile, breaking at 300 pounds, after a deflection of 0.345 inch. The load of 100 pounds produced a set of 0.118 inch, and the elastic limit was reached at the same load. The fracture showed a coarse granular, crystalline structure and a very light-gray color.

Bar No. 23 (15.08 copper, 84.62 tin) was weaker and more ductile than No. 22. It broke at 270 pounds, after a deflection of 0.858 inch. A load of 50 pounds produced a set of 0.0095 inch, and the elastic limit was reached at 60 pounds. "Time-tests," lasting one and two minutes, were made at various loads greater than 170 pounds, showing increase of deflection with each test. The fracture was light grayish-white, with large crystalline structure, almost precisely similiar in appearance to No. 19, which varied from it in composition more than 20 per cent.

Bar No. 24 (11.49 copper, 88.47 tin).—This bar was a little stronger, and very much more ductile, than No. 23. It broke at 300 pounds, after a deflection of 5.849 inches. A set of 0.01 inch was probably given by a load of 85 pounds, the reading for 75 pounds being 0.0063 inch, and for 100 pounds 0.205 inch. The limit of elasticity appears to have been passed at 75 pounds. At 200 pounds the deflection increased in one minute from 0.341 to 0.436 inch; at 270 pounds it increased in two minutes from 0.975 to 1.502 inches, and at 290 pounds it increased in one minute from 2.128 to 2.562 inches. When 300 pounds was placed on the bar, it sank down rapidly and broke in about 20 seconds, the deflection increasing before breaking from 2.739 to 5.849 inches.

Bar No. 25 (8.57 copper, 91.39 tin).—This bar showed a less strength than No. 24, with greater ductility. It broke at 160 pounds, after being left under that stress for several hours. A set of 0.0118 inch was produced by a load of 60 pounds, and the elastic limit was apparently reached at 40 pounds. When 100 pounds was placed on the bar, the deflection was observed to increase with the time it was allowed to remain, showing an increase of deflection of 0.021 inch in 10 minutes. "Time-tests" made with the loads of 100, 120, 140, and 160 pounds with like results, 140 pounds being left on the bar for more than 40 hours, increasing the deflection from 0.221 to 1.277 inches. One hundred and sixty pounds was left on the bar for more than 50 hours, increasing the deflection from 1.294 to 5.207 inches, the rate of increase at first decreasing, then remaining constant for several hours, and finally increasing. The bar was fianlly left over night, under a load of 160 pounds, with a deflection of 5.207 inches, and found broken the next morning, the bend left in the bar after breaking indicating that a deflection of nearly 8 inches had been given to the bar before fracture. The fracture showed a fine granular structure.

The records of bars No. 24 and No. 25 show that the ultimate breaking weight of such ductile metals depends in a very great degree upon the time during which they are left under stress. The duration of the test of bar No. 24 was about one hour, that of bar No. 25 was more than four days. As the breaking load of No. 25 was left on the bar for more than two days before rupture took place, it is inferred that a much greater load would have been required to break the bar in 20 seconds, the time required to break bar No. 24. In the case of bar No. 25 it would appear, from the fact that large increase of deflection was produced by various loads remaining on the bar for one or two minutes, that a much smaller load than 300 pounds would have broken the bar had it been allowed to act for a sufficient length of time.*

Bar No 26 (3.72 copper, 96.31 tin).—This bar was apparently stronger than No. 25, very probably in consequence of the greater rapidity of the test, no load being left on the bar for a greater length of time than three minutes. A set of 0.0166 inch was produced by the load of 60 pounds, and the elastic limit appeared to have been reached at 40 pounds. At 100 pounds the deflection was greater than that of bar No. 25 with the same load, indicating it to be a weaker bar. No "time-test" was made until 200 pounds was applied. This load produced a large increase of deflection in three minutes. The bar finally bent under a load of 210 pounds, with a total deflection of nearly 8 inches, and was so ductile that it required to be cut partly through and bent repeatedly in order to break it.

Bar No. 27 (0.74 copper, 99.02 tin).—This bar was much weaker than

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*These modifications in method of testing were made to secure data for other investigations by the writer. See appendix for papers by the write, rin which these phenomena are discussed at length and for strain-diagrams illustrating them.—R. H. T.

No. 26, with equal or greater ductility, taking a set of 0.02 inch at 50 pounds, reaching the elastic limit at 40 pounds, and bending to a total deflection of 8 inches at 120 pounds. Several "time-tests" were made, causing the bar to show less strength than it otherwise would have done.

Bar No. 28 (0.32 copper, 99.46 tin).—This bar proved somewhat stronger than No. 27, as the final bending load was ten pounds greater and the "time-tests" were of much longer duration. The elastic limit was apparently reached at 40 pounds, and a set of 0.014 inch took place at 70 pounds.

Bar No. 29 (all tin).—The behavior of this bar was very similar to that of bars Nos. 26, 27, and 28, but the metal was somewhat weaker and softer. A load of 40 pounds produced a set of 0.0095 inch, and the elastic limit appeared to be reached at about 30 pounds. At 80 pounds a crack was observed on one of the edges on the under side of the bar, which gradually opened but did not increase in length. At 110 pounds the bar sank gradually, the deflection increasing more than 6 inches in ten minutes. The bar was finally broken by repeated bending, and showed that the crack above mentioned was produced by an imperfection in the casting, about one-fourth of the surface, or that portion in which the crack was observed, showing radiated lines of cooling and the remainder the close pasty appearance peculiar to tin ruptured by bending. The crack no doubt weakened the bar, as the final bending was resisted by but little more than three-fourths of the section.

Bar No. 30 (all copper).—This bar was made subsequently to the tests above described, and proved to be a much better bar than No. 1. It was cast in a cold iron mold, and poured when at a dazzling white heat. The surface was quite free from blow-holes, and in all respects the bar appeared to be sound. It is therefore taken as the standard bar of copper in this series of experiments. It was tested in a special transverse testing-machine, which will be described in connection with the account of the second series of copper-tin alloys, which latter were all tested with it. A remarkable difference was observed in softness and ductility between this bar and bar No. 1, the latter breaking at 650 pounds after a deflection of 0.707 inch, while the former had a deflection of 1.37 inches at 600 pounds, 3.49 inches at 800 pounds, and sustained finally a deflection of about 8 inches before breaking. This softness was indicated at the beginning of the test by the low limit of elasticity, which was 120 pounds, while in bar No. 1 it was at 225 pounds. A set of 0.01 inch took place in bar No. 1 at 250 pounds, but in bar No. 30 at less than 200 pounds. The breaking load of this bar is taken at 800 pounds, since this load produced a deflection of 3.49 inches. The fracture (Fig. 4) showed a homogeneous and compact metal, entirely free from blow-holes, with fine but very distinctly defined lines of cooling, perpendicular to each edge.

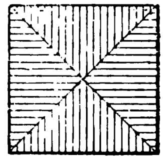

FIG. 4.

APPEARANCE OF THE FRACTURES.

After completing the tests by transverse stress, pieces were cut from each bar showing the transverse fracture. These pieces were examined by Prof. A. R. Leeds, of the Stevens Institute of Technology, who made the following report concerning their colors and structures:

DESCRIPTION OF THE SURFACES OF FRACTURE OF A SERIES OF ALLOYS OF COPPER AND TIN BROKEN BY TRANSVERSE STRESS.

BY PROF. ALBERT R. LEEDS.

No. 1 (all copper).—Color, copper red, altering by exposure to air into purple by film of suboxide, and into black by film of oxide of copper.

Surface in part large vesicular, in part curvilinear fibrous. Maximum diameter of vesicles, 7 mm.; maximum breadth of fibers, 1.5 mm.; length, 8 mm.

No. 2 (97.89 copper, 1.90 tin).—Color, red, slightly oxidized by exposure. Large and coarse vesicular; maximum diameter of vesicles, 5 mm.

No. 3 (96.06 copper, 3.76 tin).—Color, bright, reddish-yellow, with faint traces of black oxide from exposure. Surface, small and finely vesicular.

No. 4 (92.11 copper, 7.80 tin).—Color, dull reddish-yellow. Homogeneous. Surface, finely aborescent.

No. 5 (90.27 copper, 9.58 tin).—Color, reddish-yellow, with spots of dark red and bright yellow. Surface, not homogeneous, in part vesicular, in part finely fibrous.

No. 6 (87.15 copper, 12.73 tin).—Color, brass-yellow in part, in part bluish white. Surface, not homogeneous, finely vesicular. Fracture, hackly.

No. 7 (80.95 copper, 18.84 tin).—Color, reddish-gray, with brass-yellow spots. Surface, reticulated fibrous.

No. 8 (76.64 copper, 23.24 tin).—Color, reddish-gray. Surface, faintly vesicular; interior of vesicles brass-yellow. Fracture, irregularly curved. Luster, dull.

No. 9 (69.84 copper, 29.89 tin).—Color, grayish-white. Surface, crystallization prismatic, diverging from center. Fracture, of large curvature. Luster, glistening.

No. 10 (68.58 copper, 31.26 tin).—Color, grayish-white, more white than the preceding. Surface, crystalline prismatic, diverging from the center. Fracture, of large curvature. Luster, glistening.

No. 11 (65.34 copper, 34.47 tin).—Color, bluish-gray, showing yellowish spots in some lights. Surface, interruptedly crystalline. Fracture, coarsely rounded. Luster, splendent.

No. 12 (62.31 copper, 37.35 tin).—Color, dark bluish-gray. Surface, laminated. Fracture, coarse hackly. Luster, splendent.

No. 13 (56.70 copper, 43.17 tin).—Color, bluish white. Surface, crystallization eminent; crystals prismatic and diverging from center. Luster, splendent.

No. 14 (51.62 copper, 48.09 tin).—Color, bluish-white. Surface, crystallized, but not readily apparent. Fracture, coarse anguler. Luster, splendent.

No. 15 (47.61 copper, 52.14 tin).—Color, grayish-white. Surface, finely granular. Fracture, waved. Luster, glistening.

No. 16 (44.52 copper, 55.28 tin).—Color, grayish-white. Surface, laminated granular. Fracture, coarsely waved. Luster, glistening.

No. 17 (42.38 copper, 57.30 tin).—Color, grayish-white. Surface, crystallization finely reticulated. Fracture, uneven. Luster, glistening.

No. 18 (38.37 copper, 61.32 tin).—Color, grayish-white. Surface, crystallized. but not readily apparent. Fracture, coarse hackly. Luster, bright.

No. 19 (34.22 copper, 65.80 tin).—Color, grayish-white. Surface, crystallization eminent, prismatic, and diverging from center. Prismatic angle, 130°. Sides of prism doubly striated, one set of striæ parallel to edge of prism, the other at an angle of 47° with the former. Luster, splendent.

No. 20 (25.85 copper, 73.80 tin).—Color, grayish-white. Surface, crystallization eminent, prismatic. Luster, splendent.

No. 21 (23.35 copper, 76.29 tin).—Color, grayish-white. Surface, crystallized, but not readily apparent. Fracture, hackly. Luster bright.

No. 22 (20.25 copper, 79.63 tin).—Color, grayish-white. Surface, crystallization not large but eminent; prismatic diverging from center. Prismatic angle, 107°. Luster, splendent.

No. 23 (15.08 copper, 84.62 tin).—Color, grayish-white. Surface, crystallization, coarse with prismatic faces, divergent. Fracture, jagged. Luster, splendent.

No. 24 (11.49 copper, 88.47 tin).—Color, grayish-white. Surface, crystallization finely reticulated. Fracture, hackly. Luster, dull, with bright reflections from scattered crystalline faces. Section, distorted.

No. 25 (8.57 copper, 91.39 tin).—Color, grayish-white. Surface, granular. Luster, dull, with glistening points. Section, distorted with curved edges.

No. 26 (3.72 copper, 96.31 tin).—Color, grayish-white. Surface, rounded granular. Luster, dull.

No. 27 (0.74 copper, 99.02 tin).—Color, grayish-white. Surface, crystallization feeble with undefined prismatic faces. Luster, bright.

No. 28 (0.32 copper, 99.46 tin).—Color, grayish-white. Surface, irregularly waved. Luster, dull.

No. 29 (all tin).—Color, bluish or grayish-white. Surface, slightly vesicular at center, prismatic at edges. Section, much distorted. Luster, bright.

TESTS BY TENSILE STRESS.

The bars broken by transverse stress were afterward tested by tension, two tension pieces being made from each bar, one from the upper and one from the lower end.

Each bar was marked with the letters A, B, C, D in addition to its number for the purpose of distinguishing different portions of the bar. The upper end of the bar was marked A, the lower end B, and the middle C and D, respectively, above and below the transverse fracture. The pieces tested by tension are distinguished in the records which follow, by the same number which was borne by the bar from which they were made and by the letters A or B, as the piece was taken from the upper or lower end of the bar.

The pieces to be tested were made of the shape and size indicated in the diagram below, whenever the sizes of the pieces from which they were cut were sufficient to allow it.

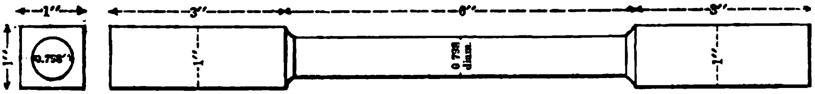

FIG. 5.

When the broken bar from which the test-piece was made was not long enough to make the piece of the size shown above, the cylindrical portion was shortened, leaving the square ends at least 3 inches in length. The cylindrical portion was turned with great care to a diameter of 0.798 inch, thus giving a sectional area of one-half square inch.

The pieces numbered No. 1 to No. 8 (all copper to 76.64 copper, 23.24 tin), inclusive, were turned in the lathe without difficulty, a gradually increasing hardness being noticed, the last named giving a very short chip, and requiring frequent sharpening of the tool. The turned surface of all these bars was made perfectly smooth by the turning tool. The color of the turned surface varied from copper-red to light golden-yellow, the color gradually becoming lighter with the increase of percentage of tin. In turning these bars, blow-holes of various sizes were found in nearly all of them, No. 4 and No. 7 only being quite free from them; No. 1 and No. 2 had a very large number of all sizes, and Nos. 3, 5, 6, and 8 had each a few, usually of small size.

With the most brittle alloys it was found impossible to turn the test-pieces in the lathe to a smooth surface. No. 9 to No. 11 (29.89 to 34.47 tin) could not be cut with a tool at all. Chips would fly off in advance of the tool and beneath it, leaving a rough surface, or the tool would sometimes apparently crush off portions of the metal, grinding it to powder. These bars were not turned down to the standard size, 0.798 inch, but had the corners merely taken off, making the cylindrical portion nearly 1 inch diameter and 1 inch long.

No. 12 B (36.96 tin) gave even more trouble than No. 9 to No. 11. The piece broke in the lathe before the corners were taken off. No. 12 A was left for test without being turned.

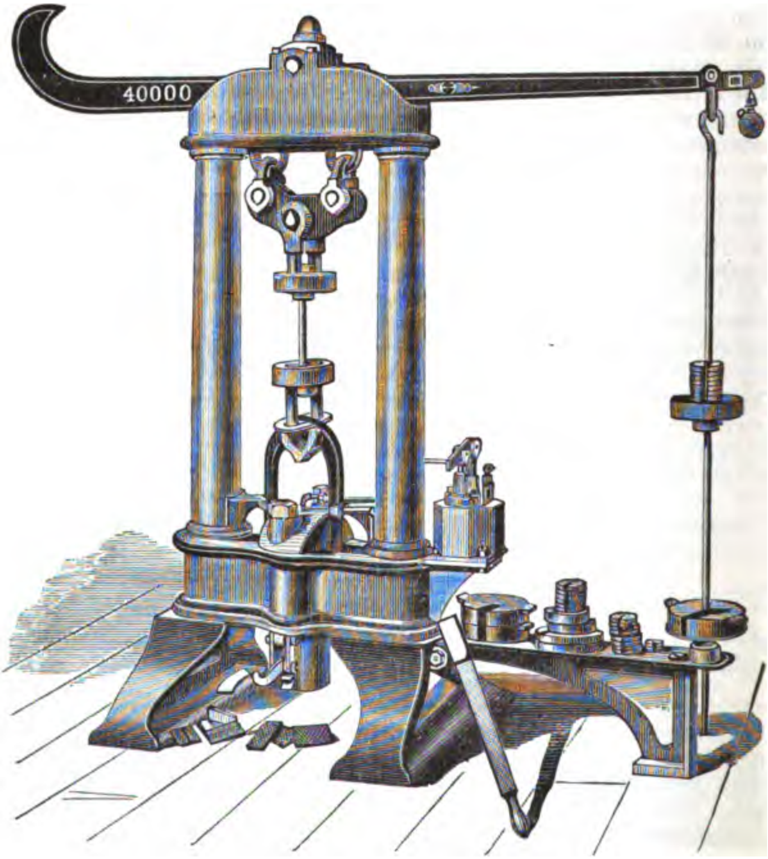

FIG. 6.

No. 13 and No. 14 (43.17 and 48.09 tin) worked like No. 9 to No. 11. No. 14 B (38.41 copper, 61.04 tin) proved to be much softer and more easily turned than No. 14 A (62.27 copper, 37.58 tin), and was turned to the standard diameter. No. 14 A was as hard as No. 12. This was due to the difference in composition of the two ends of this bar, as before described, the larger proportion of tin being at the bottom.

No. 15 was much softer than No. 13, but not so soft as No. 14 B. It was, however, very weak, and broke in the lathe before being finished, No. 15 A was left without being turned.

No. 16 worked like No. 15, the tool taking off very fine chips and powder.

No. 17 was a little softer, chips from the tool being easily reduced to powder by being rubbed between the fingers. No. 17 A (45.93 copper, 53.80 tin) was somewhat harder than No. 17 B (38.83 copper, 60.79 tin), which was due, as in the case of No. 14, to liquation.

No. 18 to No. 20 worked like No. 17 B, the chips being very weak and brittle.

No. 21 was not turned, on account of the cavity which extended through its length.

No. 22 to No. 29 all worked very easily in the lathe, showing increasing softness as the proportion of tin increased.

The apparatus used in the tests by tensile stress was the testing machine in the Mechanical Laboratory of the Stevens Institute of Technology, a cut of which is shown on preceding page.

The elongations were measured by means of a pair of finely-pointed dividers, with a fine screw-attachment, taking the distances between two points marked on the cylindrical portion of the test-piece, about 5 inches apart. The distances taken by the dividers were then measured on a standard scale, divided to hundredths of an inch. In this way the smallest elongation which could be observed was 0.01 inch, which was probably in many cases beyond the elastic limit, so that from these experiments neither the elastic limit nor the modulus of elasticity within that limit could be accurately determined. As a close approximation, however, the elastic limit is taken from the curves of elongations, the point at which the curves appear to change their direction toward the horizontal being considered to indicate the limit.

Tables giving the record of the test of each bar are appended. The following is a summary of the results:

TABLE III.—FIRST SERIES—COPPER AND TIN ALLOYS.

Tests by Tensile Stress.

No.	Composition by analysis.		Diameter.		Total elongation—parts of original length.	Tenacity per square inch.		Elastic limit—pounds per square inch.	Remarks.
	Copper.	Tin.	Original section.	Fractured section.		Original section.	Fractured section.		
			Inches.	*Inches.*		*Pounds.*	*Pounds.*		
1 A ...	Cast copper		0.798	0.790	0.0060	14,180	14,464	12,000	
1 B....	......do	....	0.798	0.742	0.0033	11,340	11,509	10,000	
Mean ..	....	....	....	0.766	0.0047	12,760	12,987	11,000	
2 A ...	97.95	1.88	0.798	0.730	0.1566	25,200	30,104	10,000	
2 B....	97.83	1.92	0.798	0.717	0.1100	23,960	29,142	10,000	
Mean ..	97.89	1.90	....	0.724	0.1333	24,580	29,623	10,000	
3 A ...	96.16	3.71	0.798	0.696	0.1317	30,960	40,687	16,000	
3 B....	95.96	3.80	0.798	0.686	0.1540	33,040	44,696	16,000	
Mean ..	96.06	3.76	....	0.691	0.1429	32,000	42,692	16,000	
4 A ...	92.14	7.84	0.798	0.730	0.0780	29,300	35,002	20,000	
4 B....	92.07	7.76	0.798	0.737	0.0325	27,780	32,559	18,000	
Mean ..	92.11	7.80	....	0.734	0.0553	28,540	33,780	19,000	
5 A ...	90.11	9.66	0.798	0.745	0.0412	26,720	30,649	15,000	
5 B....	90.43	9.50	0.798	0.760	0.0319	27,000	29,761	16,500	
Mean ..	90.27	9.58	....	0.753	0.0366	26,860	30,205	15,750	
6 A ...	87.15	12.69	0.798	0.792	0.0185	26,700	27,098	20,000	
6 B....	87.15	12.77	0.798	0.773	0.0480	32,160	34,263	20,000	
Mean ..	87.15	12.73	....	0.783	0.0333	29,430	30,680	20,000	
7 A ...	80.99	18.92	0.798	0.798	0.004	33,600	33,600	....	
7 B....	80.90	18.75	0.798	0.798	0.004	32,360	32,360	....	
Mean ..	80.95	18.84	....	0.798	0.004	32,980	32,980	....	
8 A ...	76.67	23.24	0.798	0.798	0	20,600	20,600	20,600	
8 B....	76.60	23.23	0.798	0.798	0	23,420	23,420	23,420	
Mean ..	76.64	23.24	....	0.798	... .	22,010	22,010	22,010	
9 A ...	69.90	29.85	0.985	0.985	0	7,006	7,006	7,006	
9 B....	69.77	29.92	0.972	0.972	0	4,164	4,164	4,164	
Mean ..	69.84	29.89	....	0.979	....	5,585	5,585	5,585	
10 B....	68.57	31.30	....	....	0	1,620	1,620	1,620	Rectangular section 0.994″ × 1.005″.
11 A ...	65.31	34.47	0.974	0.974	0	2,376	2,376	2,376	
11 B....	65.36	34.47	0.975	0.975	0	2,025	2,025	2,025	
Mean ..	65.34	34.47	....	....	....	2,201	2,201	2,201	
12 A ...	61.83	37.74	....	....	0	250	250	250	
12 C....	62.79	36.96	....	....	0	1,125	1,125	1,125	
Mean ..	62.31	37.35	....	....	....	688	688	688	
13 A ...	56.58	43.11	....	....	0	1,259	1,259	1,259	Rectangular section 0.998″ × 1.004″.
13 B ...	56.82	43.22	0.975	0.975	0	1,650	1,650	1,650	
Mean ..	56.70	43.17	....	....	....	1,455	1,455	1,455	
14 A ...	62.27	37.58	0.968	0.968	0	1,170	1,170	1,170	
14 B ...	38.41	61.04	0.798	0.798	0	3,940	3,940	3,940	
Mean ..	51.62	48.09	... .	....	....	2,555	2,555	2,555	
15 A ...	47.72	51.99	1.055	square.	0	950	950	950	
15 C....	"	"	"	"	0	2,100	2,100	2,100	
Mean ..	47.61	52.14	....	....	....	1,525	1,525	1,525	
16 A ...	44.62	55.15	0.980	0.980	0	3,460	3,460	3,460	
16 B....	44.42	55.41	0.798	0.748	0	2,560	2,560	2,560	
Mean ..	44.52	55.28	....	....	....	3,010	3,010	3,010	
17 A ...	45.93	53.80	0.798	0.748	0	2,260	2,260	2,260	
17 B....	38.83	60.79	0.798	0.748	0	5,560	5,560	5,560	
Mean ..	42.38	57.30	....	....	....	3,910	3,910	3,910	
18 A ...	38.37	61.32	0.798	0.748	0	....	....	....	Broke before test.
18 B....	38.37	61.32	0.798	0.748	0	2,820	2,820	2,820	

Tests by tensile stress—Continued.

No.	Composition by analysis.		Diameter.		Total elongation—parts of original length.	Tenacity per square inch.		Elastic limit—pounds per square inch.	Remarks.
	Copper.	Tin.	Original section.	Fractured section.		Original section.	Fractured section.		
			Inches.	*Inches.*		*Pounds.*	*Pounds.*		
19 A ...	34.22	65.80	0.798	0.748	0	....	....	....	Broke before test.
19 B ...	34.22	65.80	0.799	0.799	0	3,371	3,371	3,371	
20 A ...	26.57	73.08	0.799	0.799	0	1,795	1,795	1,795	
20 B....	25.12	74.51	0.798	0.798	0	1,500	1,500	1,500	
Mean ..	25.85	73.80	....	....	....	1,648	1,648	1,648	
21 A ...	22.80	76.89	0.997	0.997	0.0017	6,275	6,275	6,275	Rectangular section 0.997″ × 1.007″.
21 B....	23.89	75.68	1.000	1.000	0	7,275	7,275	7,275	Rectangular section 1″ × 1.02″.
Mean ..	23.35	76.29	....	....	....	6,775	6,775	6,775	
22 A ...	20.28	79.63	0.798	0.798	0	6,440	6,440	6,440	
22 B....	20.21	79.62	0.799	0.799	0	2,334	2,234	2,234	
Mean ..	20.25	79.63	....	....	....	4,337	4,337	4,337	
23 A ...	15.12	84.58	0.798	0.798	0	550	550	550	Result doubtful.
23 B....	15.04	84.65	0.798	0.798	0.0067	6,520	6,520	5,500	
Mean ..	15.08	84.62	....	....	0.0067	6,520	....	....	
24 A ...	11.49	88.44	0.798	0.768	0.0740	6,600	7,050	3,000	
24 B....	11.48	88.50	0.798	0.795	0.008	6,160	6,204	4,000	
Mean ..	11.49	88.47	....	0.782	0.0410	6,380	6,627	3,500	
25 A ...	8.82	91.12	0.798	0.730	0.0714	6,000	7,167	3,500	
25 B....	8.32	91.66	0.798	0.740	0.0660	6,900	8,021	3,500	
Mean ..	8.57	91.39	....	0.735	0.0687	6,450	7,594	3,500	
26 A ...	3.70	96.30	0.798	0.680	0.0983	4,300	5,920	2,500	
26 B ...	3.74	96.32	0.798	0.660	0.148	5,260	7,687	3,000	
Mean ..	3.72	96.31	....	0.670	0.1232	4,780	6,804	2,750	
27 A ...	0.75	98.98	0.798	0.550	0.316	3,600	7,576	....	
27 B....	0.72	99.06	0.798	0.540	0.1397	3,700	8,157	....	
Mean ..	0.74	99.02	....	0.545	0.2279	3,650	7,867	....	
28 A ...	0.32	99.46	0.798	0.455	0.3600	4,700	14,453	2,500	Tenacity of fractured section doubtful.
28 B....	0.32	99.45	0.798	0.475	0.3448	4,250	11,992	2,500	Do.
Mean ..	0.32	99.46	....	0.465	0.3544	4,475	13,223	2,500	
29 A ...	Cast	tin.	0.798	0.490	0.2833	2,800	....	....	
29 B....	"	"	0.798	0.300	0.4269	4,200	....	....	Do.
Mean ..	....	....	....	0.395	0.3551	3,505	....	....	
30 A ...	Cast	copper.	0.798	0.725	0.0752	29,200	34,790	14,000	
30 B ...	"	"	0.798	0.740	0.0541	26,400	30,201	14,000	
Mean ..	....	....	....	0.733	0.0647	27,800	32,496	14,000	

TESTS BY TENSILE STRESS.

The results of the tests by tensile stress agreed in general very closely with those by transverse stress, the relative strength and ductility of the various bars being the same under either kind of test. This is very plainly shown by an inspection of the curves in Plate VIII, in which the transverse and tensile strengths and the ductility are compared.

Bar No. 1 (all copper) proved deficient in both strength and ductility, in consequence of the presence of a large number of blow-holes. The fact should be kept in mind throughout this discussion of results that these cast pieces were purposely used, although frequently unsound, as it was intended to ascertain the value of each alloy as cast. It will subsequently be determined how far the occurrence of unsoundness in casting can be avoided by special treatment, and how the tenacity and other valuable properties may be thus improved. No. 1 A had a tenacity of 14,180 pounds per square inch, and No. 1 B, 11,310 pounds, with total elongations of only 0.03 and 0.02 inch respectively. The contrast between the properties of No. 1 and No. 30 is as plainly shown in the tensile as in the transverse tests, the latter having a tenacity of 29,200 and 26,400 pounds in the A and B ends respectively, with elongations of 0.376 inch and 0.271 inch. The tensile strength of No. 30 A is unusually high for cast copper.

Bar No. 2 (97.89 copper, 1.90 tin) was very much more ductile than No. 1, but was rendered deficient in strength by blow-holes.

Bar No. 3 (96.06 copper, 3.76 tin) was stronger and more ductile than No. 2. The fractures of No. 3 A and No. 3 B both showed blow-holes, which probably decreased their strength.

Bars No. 4 and No. 5 (7.80 and 9.58 tin) showed an exception to the rule of increase of strength with increase in the proportion of tin, and were both weaker under tensile stress than No. 3, while in the transverse tests No. 3 was the weakest and No. 5 the strongest of the three bars. The reason of this weakness does not appear to be the presence of blowholes, as No. 3 had more of these than either No. 4 or No. 5. In the case of No. 5 the weakness is probably due to the want of homogeneity of the metal. As observed in the notes on transverse tests, the fracture by transverse stress was not homogeneous, the central portion being dark-red or brownish-red, while the outer portions were of a reddish-yellow to yellowish-gray color.

In the fractures under tensile tests these same contrasts of color were also observed, varying slightly from those of the transverse fracture. The yellowish colored metal being partly cut away in turning the cylindrical test-piece, the section left was composed of a larger proportion of the dark-colored metal, which was probably weaker than the other. The dark color appeared as if it might have been due to oxidation of the copper, rather than to the formation of a distinct alloy of the pure metals, as no alloy of the whole series in any way resembled the central portion of bar No. 5 in color.

The more rapid cooling of the metal at the surface than in the center may have made the exterior portions the stronger, and these having been cut away by turning the tension pieces, this may account for the weakness of the latter.

Bar No. 6 (87.15 copper, 12.73 tin) showed a marked difference in tenacity in the upper and lower parts of the bar, No. 6 A (87.15 copper, 12.96 tin) breaking at 26,700 pounds per square inch, and No. 6 B (87.15 copper, 12.77 tin) at 32,160 pounds. A small blow-hole appeared in the fracture of No. 6 A, but it was not large enough to account for the difference in strength. The cause is more probably the difference of structure of the metal in the two ends of the bar. The fracture of No. 6 A was like the transverse fracture in appearance, coarse, granular, and mottled in color. No. 6 B was also mottled, but much more finely, a close observation only revealing the two distinct colors of the metal. The structure was also much more compact. The analysis of the turnings from each of these pieces shows the composition to be almost precisely the same. The difference in structure may have been caused by the difference in pressure at the top and bottom of the mold.

Bar No. 7 (80.95 copper, 18.84 tin) was the strongest of the series, the results of the tensile tests agreeing with those of the transverse tests. The tension-pieces showed but little ductility, both breaking after an elongation of only 0.02 inch. No. 7 A (80.99 copper, 18.92 tin) showed a lack of homogeneity in color, and was somewhat weaker than No. 7 B (80.90 copper, 18.75 tin).

Bar No. 8 (76.64 copper, 23.24 tin) was much weaker than No. 7, and had so little ductility that no elongation amounting to 0.01 inch could be detected. The fractures were similar to the transverse fracture, with several very small blow-holes. Bars No. 8 to No. 20 (23.24 to 73.80 tin), inclusive, had all such exceedingly slight ductility that none of them elongated 0.01 inch tensile stress. Their comparative ductility, therefore, cannot be determined from these tests. The fact of their having such a small degree of ductility, moreover, unfits them for any use in which strength is required, and their comparative ductility is of no practical value.

Bars No. 9 and No. 10 (29.89 and 31.26 tin) were so hard that great difficulty was experienced in holding them in the grip-blocks of the tensile machine. These grip-blocks were made of very hard cast steel, and the gripping edges were scored like a file. Instead of cutting into the metal of No. 9 and No. 10, as they did with all metals softer than hardened steel, they ground off the surface and let the pieces slip out.

No. 9 A was turned in the middle portion to the cylinder form, and was 1 inch long and 0.985 inch in diameter. It broke, however, in the square end of the specimen, about 1 inch from the end of the turned portion, thus fracturing a section which was one-third larger than the minimum section of the piece. This phenomenon took place also in bar No. 13 (56.70 copper, 43.17 tin), and may indicate planes of weakness in portions of the test piece or the existence of internal strains greater in some portions of the pieces under test than in others.

All of the brittle pieces showed not only general weakness but irregularity of strength. The upper and lower portions of the bar often gave very different results, and differed so irregularly that they seemed to follow no law whatever. The tensile strength of pieces of which the chemical analyses showed similar constitution, as well as the appearance of the metal, often gave widely-varying results.

Bars No. 11 to No. 20 (34.47 to 73.80 tin) all exhibited similar deficiency of strength. The peculiarities of each are given in the notes in the appended tables under the record of the test of each bar. The minimum average strength was shown by bars No. 12 and No. 13 (37.35 and 43.17 tin) corresponding to the results of the transverse tests. From No. 13 to No. 21 there was a somewhat irregular increase of strength, No. 21 giving a second maximum point of strength in the series as occurred with the transverse tests.

Bar No. 21 (23.35 copper, 76.29 tin) was tested at its original square section, on account of the existence of a cavity through its center, before described. No. 21 A showed some indications of ductility, an elongation of 0.01 inch being observed.

Bar No. 22 (20.25 copper, 79.63 tin) showed no elongation amounting to 0.01 inch. No. 22 A (20.28 copper, 79.63 tin) was nearly three times as ductile as No. 22 B (20.21 copper, 79.62 tin).

Bars No. 23 to No. 29 (84.62 to all tin) showed regularly increasing ductility, No. 23 B breaking after an elongation of 0.02 inch and No. 29 B after an elongation of 2.58 inches.

Bar No. 23 A gradually elongated under the load of 3,300 pounds for two minutes before breaking, the elongation increasing from 0.13 to 0.37 inch. This "time-test" showed the same result as those given in the tests by transverse stress, viz, that the ductile metals may show a greater or a less resistance to stress as the load is applied for a shorter or a longer time.*

The ductile bars showed a much greater uniformity of strength in the upper and lower portions of the bars than the brittle pieces, when the time occupied by the test was the same.

"Time-tests" of shorter duration were made with nearly all the bars from No. 23 to No. 29, with the uniform result of increasing the elongation. With No. 29 A a special "time-test" was made to determine the difference in resistance to slow and rapid rupture. This bar being composed entirely of tin, and apparently a good casting, it would be expected that tests of the two pieces, one from the upper and one from the lower end of the bar, would show little, if any, difference in strength. No. 29 A was first tested with a load of 1,700 pounds, which caused an elongation of 0.15 inch. This load was then reduced to 1,250 pounds, and the reading again taken, showing an elongation of 0.19 inch, which increased in two minutes to 0.27 inch. The load was then increased to 1,400 pounds, and the elongation was 0 32 inch. The load was allowed to remain on the bar for ten minutes, and the elongation gradually increased to 1.70 inches, when the bar broke. It seems probable from this test that the load of 1,400 pounds would have broken the piece even if the load of 1,700 pounds had not been placed on it at the beginning of the test.

Bar No. 29 B was then tested in a different manner. The load was gradually but rapidly increased to 2,100 pounds, without stopping longer than a sufficient time to take the reading of the elongation at 975, 1,180, 1,290, 1,600, and 2,000 pounds. At 2,100 pounds the elongation was read, 1.88 inches. The piece then extended very rapidly, and at the same time its resistance, as measured by the scale-beam, reduced to 1,700 pounds. The pump of the hydraulic press was run as fast as possible, but the beam could not be balanced by so doing beyond 1,700 pounds. The piece sustained this load a few seconds, and then broke after an elongation of 2.58 inches.

Comparing these two tests, it is seen that the resistance of No. 29 A to an elongation greater than 0.19 inch was never greater than 1,400 pounds, while that of No. 29 B was 2,100 pounds, or 50 per cent. more than the former; which 50 per cent. apparent increase of strength may have been entirely due to the greater rapidity of the test of No. 29 B and not to its inherent strength. The fact that the difference in strength is only apparent is confirmed by the experiments by torsional stress on pieces from the same bar, which are hereafter described. These showed that torsion-pieces No. 29 A and No. 29 B, one from the top the other from the bottom of the bar, each tested by a moderately slow motion, each gave a resistance of 142 foot-pounds torsional moment; piece No. 29 C, from the middle of the bar, tested in the same manner resisted 13.2 foot-pounds, while No. 29 D, a piece also taken from the middle of the bar and originally adjoining No. 29 C, tested by very slow motion and left under stress for many hours, resisted only 9.2 foot-pounds or about 30 per cent. less than either of the other pieces.

The strength per square inch of fractured section is given in the tables for the purpose of comparison, but it is not an indicator of either the ultimate or the useful strength of the metals, except in those which have but a limited degree of ductility and which do not show increase of elongation under continued stress. In the cases of ductile metals, the portion of the test-piece just above and below the point of fracture gradually narrowed down as the breaking load was reached, and in most cases this narrowing or "necking down" was very rapid the instant before fracture. In such cases the beam of the scale often dropped a few seconds before fracture took place, showing a decrease of resistance and consequently a decrease of stress. The final rupture was caused, therefore, by some load less than the maximum load which the piece sustained before the rapid necking down commenced. In a few cases it was possible to follow the decrease of resistance to stress by balancing the scale-beam, nearly to the instant of rupture, but never entirely to it, so that the actual load sustained by the piece at the instant of rupture could not be determined. The so-called "tenacity per square inch of fractured section," found by dividing the maximum load sustained by the piece by the area of section measured after fracture, is therefore no indication of the strength of the metal. Even in the cases in which the decrease of stress was not observed, and the scale-beam dropped apparently at the same instant that rupture took place, it is not always certain that decrease of resistance does not take place first, although only a fraction of a second before rupture, nor, therefore, that the final section (measured after rupture) even sustained the load indicated by the scale-beam.

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* See paper by the writer in appendix on The Effects of Time, &c.

The following description of the fracture by tensile stress has been made by Prof. A. R. Leeds:

DESCRIPTION OF THE SURFACES OF FRACTURE OF A SERIES OF ALLOYS OF COPPER AND TIN BROKEN BY TENSILE STRESS.

BY PROF. ALBERT R. LEEDS.

No. 1 B (all copper).—Color, copper-red, with a purple film of suboxide; surface, in part large vesicular, in part crystalline, radiating toward edge.

No. 2 A (97.95 copper, 1.88 tin).—Color, copper-red; surface deeply vesicular; fracture, uneven; luster, dull, with bright points.

Bar No. 2 B (97.83 copper, 1.92 tin).—Color, copper-red, inclining toward yellow; surface, finely vesicular; fracture, uneven; luster, dull, with fine bright points.

Bar No. 3 B (95.96 copper, 3.80 tin).—Color, reddish-yellow; surface, finely vesicular, the curved surfaces interrupting; luster, dull.

Bar No. 4 B (92.07 copper, 7.76 tin).—Color, yellowish-red in part, in part reddish-yellow; surface, vesicular; luster, dull.

Bar No. 5 A (90.11 copper, 9.66 tin).—Color, yellowish-red; surface, crystallization, fibrous, radiate, finely vesicular on faces; luster, dull.

Bar No. 5 B (90.43 copper, 9.50 tin).—Color, grayish-yellow; surface, coarse vesicular; fracture, jagged; luster, dull.

Bar No. 6 A (87.15 copper, 12.69 tin).—Color, bluish-white with bright yellow spots; surface, confusedly vesicular; fracture, hackly; luster, dull.

Bar No. 6 B (87.15 copper, 12.77 tin).—Color, reddish-yellow, with bluish-gray points, producing a general impression of orange; surface broadly crystalline, with surfaces of prismatic faces finely vesicular; luster, dull, with minute bright points.

Bar No. 7 A (80.99 copper, 18.92 tin).—Color, grayish-white with yellow points; surface, not apparently crystalline; fracture, coarse hackly; luster, dull.

Bar No. 8 B (76.60 copper, 23.23 tin).—Color, yellowish-gray; surface, vesicular, with smooth intervening faces; fracture, even; luster, shining.

Bar No. 9 A (69.90 copper, 39.85 tin).—Color, yellowish-gray to bluish-gray in different lights; surface, broadly-bladed prismatic, and diverging from center; fracture, smooth; luster, splendent.

Bar No. 10 A (68.58 copper, 31.26 tin).—Color, yellow to bluish gray;

surface, broadly-bladed prismatic and diverging from center; fracture, smooth: luster, splendent.

Bar No. 11 A (65.31 copper, 34.47 tin).—Color, yellow to bluish-gray; surface, crystallized, but not readily apparent; fracture, coarsely waved; luster, splendent.

Bar No. 12 B (62.79 copper, 36.96 tin).—Color, blue; surface, coarsely waved and pitted; luster, splendent.

Bar No. 13 A (56.58 copper, 43.11 tin).—Color, bluish; surface, crystallization eminent, prismatic blades diverging from center; fracture, uneven; luster, splendent.

Bar No. 14 A (62.27 copper, 37.58 tin).—Color, bluish-gray in part, in part reddish-gray; surface, crystallized, but not readily apparent; fracture, uneven; luster, dull.

Bar No. 14 B (38.41 copper, 61.04 tin).—Color, bluish-gray; surface, crystallized but not readily apparent; fracture, coarsely waved; luster, splendent.

Bar No. 15 B (47.49 copper, 52.29 tin).—Color, bluish-gray to grayish-white; surface, waved; fracture, irregular; luster, glistening.

Bar No. 16 B (44.42 copper, 55.41 tin).—Color, grayish-white; surface, crystallized but not readily apparent, waved and feebly vesicular; luster, glistening.

Bar No. 17 B (38.83 copper, 60.79 tin).—Color, grayish-white; surface, finely waved vesicular; luster, shining, with bright points.

Bar No. 18 A (43.37 copper, 56.37 tin).—Color, grayish-white; surface, crystallization prismatic, with waved lines on prismatic faces; luster, splendent.

Bar No. 18 B (43.36 copper, 56.40 tin).—Color, grayish-white; surface, crystallized, but not readily apparent, feebly vesicular; fracture, irregular; luster, glistening, bright lines of reflection from crystalline faces.

Bar No. 19 A (40.32 copper, 59.46 tin).—Color, grayish-white; surface, crystallization eminent, prismatic; the prismatic faces large and striated; prismatic angle, 91°; luster, splendent.

Bar No. 19 B (40.24 copper, 59.44 tin).—Color, grayish-white; surface, crystallization eminent, prismatic; luster, splendent.

Bar No. 20 A (26.57 copper, 73.08 tin).—Color, grayish-white; surface, crystallization eminent, the faces in part prismatic, in part having an octahedral aspect; luster, splendent.

Bar No. 20 B (25.12 copper, 74 51 tin).—Color, grayish-white; surface, crystallized, but not readily apparent, waved and feebly vesicular; fracture, rough; luster, glistening, with bright surfaces of reflection.

Bar No. 21 B (33.89 copper, 75.68 tin).—Color, grayish-white; surface, feebly crystalline and vesicular; fracture, hackly; luster, glistening, with bright points.

Bar No. 22 A (20.28 copper, 79.63 tin).—Color, grayish-white; surface, crystallization eminent, prismatic faces irregular; luster, splendent.

Bar No. 22 B (20.21 copper, 79.62 tin).—Color, grayish-white; surface, confusedly crystalline, with prismatic faces; luster, splendent.

Bar No. 23 A (15.12 copper, 84.58 tin).—Color, grayish-white, in part with yellow tarnish; surface, crystallization eminent, broad prismatic faces, radiate; luster, splendent.

Bar No. 24 B (11.48 copper, 88.50 tin).—Color, grayish-white; surface, crystallized fibrous; fracture, hackly; luster, glistening, with bright lines of reflection from edges of crystals.

Bar No. 25 A (8.82 copper, 91.12 tin).—Color, grayish-white; surface, irregular and feebly vesicular; luster, dull.

Bar No. 26 B (3.74 copper, 96.32 tin).—Color, grayish-white; surface, fibrous, in part slightly vesicular; luster, dull.

Bar No. 27 A (0.75 copper, 98.98 tin).—Color, grayish-white; surface, fibrous; fracture, jagged; luster, dull.

PHOTOGRAPHS OF FRACTURES.

The surfaces of fracture by tensile and transverse stresses, which were submitted to Professor Leeds for description, were also photographed by him. Copies of these photographs are presented with this report.

Considerable trouble was experienced and a great deal of time consumed in mounting the pieces so as to obtain the proper effect of light and shade necessary to show the peculiarities of structure of the fractured surfaces. The best effect was finally obtained by magnifying the image of the fracture, so that the photographs were one and a half times the original size of the specimen. In general six pieces were taken at once, as it was found that if more than this number were taken. the difference in structure, and consequently in reflection of light, was such that the treatment necessary to obtain good pictures of some of the pieces was not suitable for others.

In this way twenty-two plates were made, and these were afterward combined into six groups of four plates each, and reduced to about half size, or to about three-fourths of the size of the specimens. The six plates thus formed are those submitted herewith. They are numbered from No. 1 to No. 6, and the following is a key to the arrangement of the fractures which are photographed in each:

Key to the Arrangement of Photographs of Fractures of Copper-Tin Alloys.

Plate No. 1.

1 A	28 B		
[Copper.]			
7 C	2 D	27 B	
5 B	3 D	29 C	
		[Tin.]	
21 B	21 B^2	2 D	5 A
13 A	14 B	8 D	2 C
11 C	12 B	3 D	1 D
		[Copper.]	

Plate No. 2.

18 C	15 B	8 D	6 B
18 D	16 B	7 B	6 A
17 A	17 D	7 A	5 A
20 C	19 B	5 A	2 D
20 B	19 C	4 D	2 C
22 A	22 B	3 D	1 D

Plate No. 3.

27 C	23 A		
28 B	22 B		
		Tin	15 A
29 B	1 D		
26 B	24 B		
		19 C	19
10 A	25 A		
9 A	23 A		

Plate No. 4.

3	3	29	
2	2	28	28
1	1	27	27
	14 A	26	26
14 B			
	15 A	25	25
12 B			
	12 A	24	24

Plate No. 5.

1	1	6	6
2	2	7	7
3	3	8	8
3	3	9	9
4	4	10	10
5	5	11	11

Plate No. 6.

21	21	17	17
22	22	16	16
23	23	15	15
18	18	12	12
19	19	13	13
20	20	14	14

Those numbers which have not the letters A, B, C, D annexed are fractures by transverse stress; those with letters affixed are tensile fractures, except the five pieces in the upper left-hand corner of Plate No. 1, which were fractures by torsion, and No. 15 A and No. 19 C, in Plate No. 3, the former of which is a side view, showing surface markings of crystallization. The latter was an accidental fracture, which shows a highly crystalline structure.

TESTS BY TORSIONAL STRESS.

After breaking the pieces by tensile stress, as described above, the square ends of the fractured pieces were turned into pieces suitable for tests by torsion. The standard shape and size of these torsion pieces are shown in the sketch below

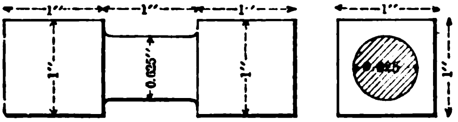

FIG. 7.

The pieces were turned with great care to a diameter of 0.625 inch, as measured by a standard gauge, and the distance between fillets and the shape of the fillets were made uniform by comparing with a standard templet. The pieces which were too brittle to be turned in a lathe were shaped by grinding with an emery-wheel in an apparatus designed for the purpose.

The pieces from each bar were marked with the letters A, B, C, D in addition to the number of the bar, these letters corresponding with those on the tension pieces, A being the piece nearest the top of the bar, B nearest the bottom, and C and D from the middle.

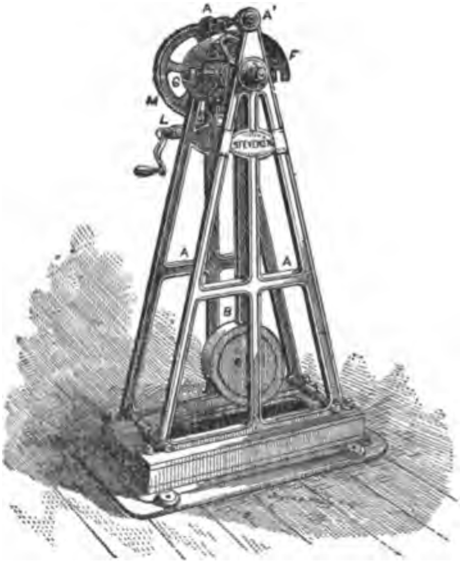

FIG. 8.

The tests by torsion were made in Prof. R. H. Thurston's machine for testing the strength, elasticity, shock-resisting power of resilience, and the homogeneousness of metal. The material is tested by twisting, by which is obtained a great range of distortion and the most favorable treatment for revealing all the characteristics of the test-piece. The latter is placed between two independent jaws, one of which is rotated by means of an arm in the simpler styles, and in the one here illustrated by a worm, L, and gear M. The force thus applied is transmitted through the test-piece to the other jaw, from which depends a weighted arm or pendulum, B. The resistance offered by this pendulum to the force tending to deflect it from the vertical, causes that force to react upon the test-piece and produce distortion and fracture. The angular position assumed by the pendulum is a measure of that force. A pencil is secured to the pendulum and is moved when the latter is thrust forward, in a direction perpendicular to the plane of rotation, by its contact with a guide-curve, F, fastened to the frame of the machine. A cylinder, G, is secured to that jaw, which is moved by the gear-wheel. The cylinder and the pencil have precisely the relative movements of the two ends of the test-piece, so that the length of the curve, automatically described by the pencil upon a paper wrapped about the cylinder, becomes a measure of the degree of distortion or of the ductility, and its height measures the resistance offered by the material.

The material thus tells its own story, these elements recording themselves simultaneously and continuously from the initial point to the point of final rupture.

The diagrams made by the machine show to the eye at a glance the nature of the material tested and are very characteristic.

In making a test with this machine, the test-piece, of the form shown on previous page, is placed in the jaws of the two wrenches, each of which takes one of its squared ends, and force being applied to the handle L, the stress thrown upon the specimen is transmitted through it to the weighted arm B, causing it to swing about its axis until the weight exerts a moment of resistance which equilibrates the moment of the applied force. As the magnitude of the distorting force changes, the position of the weight simultaneously changes, and the pencil indicates, at each instant, the value of the stress upon the test-piece. As the piece yields under stresses of increasing amount, also, the pencil is carried in the direction of the circumference of the cylinder on which its record is made, and to a distance which is proportional to the amount of distortion, *i. e.*, to the "total angle of torsion."

As the applied force increases, the specimen yields, and finally rupture occurring, the pencil returns to the base-line, at a distance from the starting-point which measures the angle through which the test-piece yielded before its fracture became complete.

Referring to the diagrams obtained in making these tests, which are appended to this report, it is seen that the vertical scale of the diagrams is a scale of torsional moments, and the horizontal scale is one of total angles of torsion. Since the resistance to shearing, in a homogeneous material, varies with the resistance to longitudinal stress, it follows that the vertical scale is also for such materials a scale of direct resistance, and that with approximately homogeneous substances this scale is approximately accurate where all specimens compared are of the same dimensions. Since the elasticity of the material is measured by the ratio of the distorting force to the degree of temporary distortion produced, the diagrams will exhibit the elastic properties of the material, as well as measure its ductility and its resilience.

It will be noticed also in these diagrams that the first portion of the line is usually a curve of small radius, convex toward the axis of abscissas, and that the line then rises at a slight inclination from the vertical, but becoming very nearly straight until, at a point some distance above the origin, it takes a reversed curvature. The first portion of the line is probably formed by the yielding of the packing-pieces securing the heads of the specimen, and, after they have taken a bearing, by the early yielding in some materials of particles already overstrained by internal stresses. When a firm hold is obtained, the line becomes nearly straight, and the amount of the distortion is seen to be approximately proportional to the distorting force, and the inclination of the line is therefore a measure of the stiffness of the material.

The point of the line where the reversed curvature takes place marks the limit of elasticity; that is, the point at which the distortion increases suddenly much more rapidly than the applied force.

The brittle metals, in which these elastic limits are not reached before fracture, also do not give in the torsion diagram any curve with reversed curvature, but the lines rise nearly straight, with a slight inclination from the vertical till fracture takes place.

The following rules are of service in interpreting the diagrams:

(1) *To determine the homogeneousness of the material.*

Examine the form of the initial portion of the diagram between the starting-point and the first sudden change of direction which indicates the elastic limit. Notice also its inclination from the vertical and compare with it the inclination of the "elasticity line."

A perfectly straight line beneath the elastic limit, perfectly parallel with the "elasticity line," shows the material to be *homogeneous as to strain; i. e.*, to be free from internal strains such as are produced by irregular and rapid cooling or by working too cold. Any variation from this line indicates the existence and measures the amount of strain. A line considerably curved exhibits the existence of such strain.

Next examine the form of the curve immediately after passing the elastic limit.

A line rising from the elastic limit regularly and smoothly, approximately parabolic in form, and concave toward the base line. indicates *homogeneousness to structure* and the absence of such imperfections as are produced in wrought iron by cinder, or in cast metals which have been worked from ingots, by porosity of the ingot.

A line turning the corner sharply when passing the elastic limit and then running nearly or quite horizontal, as in irons usually and in low steel, or actually becoming convex toward the base-line, as with some of the woods, and then after a time resuming upward movement by taking its proper parabolic path, indicates a decided want of this kind of homogeneity. The relative length of the depressed portion of the line, and the amount of depression, measure the relative defectiveness of materials compared in this respect.

Finally, compare the diagrams produced by several specimens of the same kind of material or from the same mass.

Homogeneousness in general character and *homogeneousness in composition* are proven by the precise similarity of these diagrams, while a greater or less variation of the curves compared indicates a greater or less difference in the specimens of which they are autographs.

Materials should usually exhibit great homogeneousness in all these three ways to be perfectly reliable. Perfect homogeneousness is not to be expected in either respect.

(2) *To determine the elastic resistance of the specimen.*

Measure the height of the curve at the elastic limit, using the scale of torsion, or for tension, which is given for each machine and for each standard size of test-piece.

(3) *To determine the resistance offered to any given amount of extension or that producing a given set.*

Measure the height of the curve at the point whose distance from the origin measures the assumed degree of set.

(4) *To determine the ultimate resistance of the material.*

Measure in a similar manner the maximum height of the curve.

(5) *To determine the resilience of the piece within the elastic limit, i. e.,* the work required to produce an evident and permanent set, approximately proportional in amount to the degree of change of form of the specimen. (*This quantity measures the power of the material to resist blows,* and its determination is evidently quite as important as that of resistance to simple stress, which latter forms one of the factors of the former.)

Measure the area comprised between the ordinate of the curve at the elastic-limit and the initial part of the curve. This quantity is proportional to the required value.

(6) *To determine the resilience of the material within any assumed limit of extension, i. e.,* the magnitude of blow required to produce a given set.

Measure the area of the curve up to the assumed limit.

(7) *To determine the total resilience* or shock-resisting power of the material.

Measure the total area of the diagram.

For ductile metals an approximate value is obtained by taking two-thirds the product of the maximum tenacity by the maximum extension. For hard and very brittle materials one-half the same product gives very accurately its values. For intermediate qualities the true value is more nearly two-thirds this product; also Swedish wrought iron, white cast iron and hardened steel, illustrate the first and the second classes; ordinary tool-steels are examples of the third class.

(8) *To determine the effect of a load given in pounds per square inch of stress.*

Find a point in the curve having an altitude which measures the given stress, the abscissa of that point measures the extension under that load.

In other words, a point being found in the curve, the height of which above the base-line is equal to the load per square inch, its horizontal distance from the origin measures the extension of the material as produced by that stress.

In calculating the torsional moments from the diagrams the scale used was the following, the 100-pound weight being used on the arm:

$$\left.\begin{array}{c}\text{Foot-pounds of tor-}\\ \text{sional moment}\end{array}\right\} = [(\text{inches of ordinate} \times 117.443) + 11.856].$$

For resilience the following scale was used:

Resilience, in foot-pounds of work $=$ (area of diagram in square inches $\times 20.496) + ($maximum abscissa in inches $\times 1.893)$.

These scales were determined by careful experiment and measurement upon the machine used in the tests ("Standard" machine No. 7, Stevens Institute of Technology).

On comparing the autographic strain-diagrams of the torsion tests with the curves of tests by transverse and tensile stresses, made by plotting the figures of the records of the latter, Plate VIII, it will be seen that with each bar there is a very marked similarity in the shape of its curves produced by each of the three methods of test. The ductile materials, by either method of test, give curves which become nearly parallel to the axis of the abscissas long before fracture, while the brittle materials give curves in which the reversed curve, concave to the axis of abscissas, never takes place.

In testing the torsion pieces of all bars from No. 1 (all copper) to No. 8 (76.64 copper, 23.24 tin) inclusive, the weight on the end of the arm of the torsion machine was 100 pounds. In testing all the remaining metals the weight was either wholly removed and the weight of the arm alone furnished the distorting and breaking force, or a weight of 30 pounds was substituted for the 100 pounds. In calculating the strength and the resilience from the diagrams, the ordinates of the curve are multiplied by a greater or less factor according as the greater or less weight was used on the arm. The ductility of the material is measured by the angle of torsion and is independent of the weight used.

In addition to the diagrams, tables are appended giving the results of the calculations made from them, viz, the area of the diagram, with the resilience calculated therefrom; the maximum ordinate, with its corresponding maximum torsional moment, which is approximately proportional to the tensile strength of the material; the ordinate at the elastic limit, with its corresponding torsional moment, which is also approximately proportional to the tensile strength at the elastic limit; and the angle of torsion, and the extension in parts of its original length of an exterior fiber or line of particles on the surface of the cylindrical portion of the test-piece, which is calculated from the angle of torsion and is directly proportional to the ductility.

From the appended tables, to which are given the results of the calculations of the autographic diagram of each test-piece, a condensed table has been made, which is given below, which gives the *average* of results of the several test-pieces from each bar. In making the averages, those tests which are evidently unsatisfactory, from the presence of large blow-holes in the center of the test specimen, are rejected. In the tables at the end of the report the tests which are rejected are indicated.

TABLE IV.—TESTS BY TORTIONAL STRESS—AVERAGES OF RESULTS CALCULATED FROM THE AUTOGRAPHIC STRAIN-DIAGRAMS.

First series.—Copper and Tin Alloys.

Number.	Mean composition by analysis.		Area of diagrams.	Angle of torsion.	Ordinate.		Torsional moment.		Ductility extension of exterior fiber.	Resilience.	Number of pieces averaged.	Remarks.
	Copper.	Tin.			Maximum.	At elastic limit.	Maximum.	At elastic limit.				
			Sq. in.	*Degrees.*	*Inch.*	*Inch.*	*Ft.-lbs.*	*Ft.-lbs.*		*Ft.-lbs.*		
1	Copper.		1.30	40.5	0.47	0.19	65 06	33.17	0.0255	37.71	3	All full of blow-holes.
2	97.89	1.90	25.00	317.5	1.19	0.23	150.46	37.28	1.0006	572.51	2	
3	96.06	3.76	26.99	247.4	1.25	0.36	156.93	52.99	0.7081	599.96	4	
4	92.11	7.80	12.37	125.6	1.27	0.43	160.01	61.36	0.2189	277.22	4	
5	90.27	9.58	12.34	114.5	1.40	0.53	175.28	72.52	0.1795	274.60	2	
6	87.15	12.77	11.45	100.0	1.46	0.6	182.32	81.32	0.1391	253.61	1	
7	80.95	18.84	1.59	16.3	1.53	0.92	190.15	118.51	0.0040	35.59	3	
8	76.63	23.24	0.15	3.4	0.95	0.95	122.13	122.13	0.00017	3.72	4	
9	69.84	29.88	0.08	1.5	1.5	1.5	17.58	17.58	0.00008	0.63	1	
11	65.33	34.47	0.12	0.75	3.4	3.4	16.44	16.44	0.00002	0.36	1	
12	62.31	37.35	0.08	1.0	1.2	1.2	7.06	7.06	0.00003	0.25	1	
13	56.70	43.17	0.10	1.0	1.45	1.45	8.94	8.94	0.00003	0.41	1	
14	51.62	48.09	0.06	1.0	2 8	2.8	13.54	13.54	0.00003	0.19	1	
15	47.61	52.14	0.09	1.0	3.08	3.08	14.87	14.87	0.00003	0.28	2	
16	44.52	55.28	0.09	0.92	2.48	2.48	23.25	23.25	0.00003	0.53	3	
17	42.38	57.30	0.09	1.65	1.77	1.77	28.11	28.11	0.00007	0.60	3	
18	38.37	61.32	0.08	1.70	1.15	1.15	23.46	23.46	0.00005	0.42	3	
19	34.22	65.80	0.06	1.87	0.66	0.66	16.56	16.56	0.00005	0.31	3	
20	25.85	73.80	0.14	2.34	0.88	0.88	20.97	20.97	0.00011	0.76	4	
21	23.35	76.29	0.57	4.5	1.9	1.9	41.50	41.50	0.00030	2.25	1	
22	20.25	79.63	0.50	5 69	0.98	0.9	22.93	21.32	0.00059	2.07	4	
23	15.08	84.62	2.18	24.83	0.97	0.69	22.80	17.16	0.00092	9.05	3	
24	11.49	88.47	5.70	61.73	1.00	0.60	23.24	15.18	0.0708	23.45	4	
25	8.57	91.39	10.40	131.75	0.98	0.56	22.98	14.51	0.2347	43.85	4	
26	3.72	96.31	18.23	220.5	0.98	0.43	22.83	11.74	0.5677	76.28	2	
27	0.74	99.02	19.63	387.5	0.75	0.26	18.29	8.20	1.3388	90.40	2	
28	0.32	99.46	27.43	535.3	0.66	0.18	16.47	6.89	2.0879	125.99	3	
29	Cast tin.		21.26	55[illegible].75	0.48	0.13	12.75	5.78	2.1975	105.45	4	
30	Cast copper.		17.61	153.0	1.38	0.46	143.24	50.63	0.3084	320.35	4	

NOTES ON THE TESTS BY TORSION.

Referring to the above table, it will be seen that the relative strength and ductility of the various bars in the series, as found by the tests by torsional stress, agree closely with the tests of the same bars by transverse and tensile stress. The copper bar No. 30 shows much greater strength and ductility than No. 1, as would be expected from the spongy structure of the latter.

There is a regular increase of strength in the series to No. 7 (80.95 copper, 18.84 tin), as shown by the other tests. The strength then rapidly decreases to No. 12 (62.31 copper, 37.35 tin), the weakest of the series. The same general weakness and irregularity are observed in the bars from No. 12 to No. 20 (25.85 copper, 73.80 tin), as was shown in the tests by tensile and transverse stress. The second maximum point of strength is again given by No. 21 (23.35 copper, 76.29 tin), from which point the strength regularly decreases to No. 29 (all tin). The curves of strength of the series by tensile and torsional stresses (Plate VIII) show the close agreement of the results of the two kinds of tests.

Referring to the autographic strain-diagrams of the tests by torsion (Plates XXII to LXXVI) and to the tables of results calculated from the diagram of each piece, the following observations may be noted:

Nos. 1 A, 1 C, 1 D, Plate XXII (cast copper). All of the pieces were full of blow-holes, and the results are of no value except to show the worthlessness of this metal as ordinarily cast. For the standard tests of cast copper see No. 30.

No. 2, Plates XXII, XXIII, XXIV (97.89 copper, 1.90 tin).—The pieces marked A and B were sound and gave good results. Pieces C and D contained several blow-holes, and are rejected in the averages as defective. The fact that two of these pieces were stronger than the others, and that the weaker pieces were taken from the middle portion of the bar show the cause of the defective transverse strength, and show also that the defects in some of the bars were local and did not extend throughout the whole length. The pieces A and B show a high degree of ductility, the total angles through which they were twisted before rupture being 296 and 339 degrees respectively.

No. 3, Plates XXV, XXVI, XXVII, XXVIII (96.06 copper, 3.76 tin).—The four pieces tested give results varying from 128 to 181 foot-pounds of torsional moment. The appearance of the fractures does not indicate the reason of the variation. The strongest piece had the greatest ductility, and the next to the strongest had the least ductility.

No. 4, Plates XXVIII, XXIX (92.11 copper, 7.80 tin).—The pieces taken from the ends of the bar, marked A and B, gave the same strength, viz, 175 foot-pounds of moment, while the pieces from the middle of the bar marked C and D, gave only 140 and 149 foot-pounds respectively. The ductility varied in the same direction as the strength, the pieces from the ends having extensions about twice as great as pieces from the middle.

No. 5, Plate XXX (90.27 copper, 9.58 tin).—Both pieces from the lower half of the bar were defective. The piece marked B had a large cavity, about one inch long and nearly half an inch in diameter. The existence of this cavity was unsuspected before the test was made. The piece marked D had several small blow-holes, and a peculiar dark color, as if oxidized, similar to that which has been noted under the tensile tests of this bar. The pieces A and C were sound, and gave results nearly agreeing with each other.

No. 6, Plate XXXI (87.15 copper, 12.73 tin).—The torsional strengths of the four species varied from 134 to 182 foot-pounds. The fractures show the cause of the difference. The fractures of pieces from the upper half of the bar, A and C, show the same separation of metals which has been remarked upon in the transverse test of this bar. There are two distinct colors, golden-yellow and silver-white, mingled throughout the surface of fracture, showing liquation of the metal into two distinct alloys. The piece marked D, from the upper end of the lower half of the bar, also showed this separation, but in a much less degree, or, rather, the intermixture of the two colors was much closer and finer, so that a close inspection was required in order to recognize it. The fracture was somewhat similar to that of the tension test-piece, No. 6 B. In the torsion piece, from the lower end of the bar No. 6 B, liquation was not observable, and the fracture appeared quite homogeneous, and of a uniform golden-yellow color, similar to that of No. 5 A or C. As might be expected, this piece was the strongest of the four, its maximum torsional moment being 182 foot-pounds, while those of the pieces A, C, and D were 145, 144, and 134 foot-pounds, respectively.

The ductility of this piece (No. 6 B) was also considerably greater than that of either of the others. The shapes of the surfaces of fracture by torsional stress of the four pieces also illustrate in a marked degree their differences of properties. The pieces A and C have the irregular diagonal or conoidal fracture which is characteristic of all brittle metals and of those having only a limited amount of ductility, such as cast iron (Fig. 9), while the fracture of piece B is nearly smooth, and lies in a plane perpendicular to the axis of the specimen.

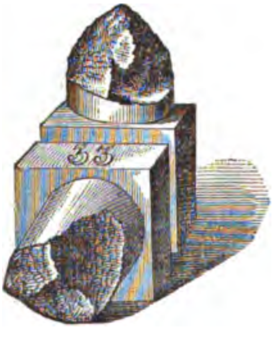

Fig. 9.

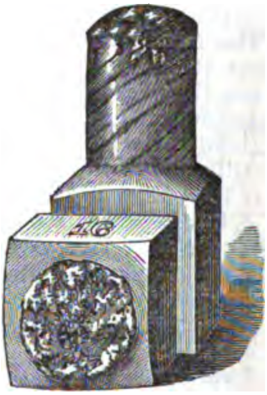

Fig. 10.

This fracture is characteristic of wrought iron (Fig. 10), and of all metals which are similarly ductile. The fracture of the piece marked D was partly diagonal and partly perpendicular to the axis, showing a structure with a character between those of pieces A and B.

The analyses of the turnings from the upper and lower halves of the bar do not show any variation in comparison which can account for the variation in structure or in strength. The composition of the original mixture was 86.57 copper, 13.43 tin, and the analyses gave for the upper half of the bar 87.15 copper, 12.69 tin, and for the lower half 87.15 copper, 12.77 tin. The difference in structure is possibly accounted for by the more rapid cooling of the metal at the lower end of the mold, which cooling would prevent a separation of the metals, or it may be that the greater pressure sustained by the molten metal at the bottom of the mold prevented such separation and rendered the metal more compact.

The liquation which is observed in this bar appears to be of a different character from that of bars Nos. 14 and 17, in which the upper end of the bar contained more copper and the lower end more tin. The variation of composition between the upper and lower halves of bar No. 14 was as great as 24 *per cent.*, and from the appearance of the metal in different portions of this bar, it was evident that the percentage of copper increased gradually from the bottom to the top, and in no part of the bar was there any appearance of a mottled mixture of two colors, as in bar No. 6.

The tests by transverse stress showed that bar No. 6 had a much less transverse strength than either No. 5 or No. 7, and if introduced in the curve of tests by transverse stress, would make a break in its regularity. The fact that the torsion piece, No. 6 B, of the same composition as the other pieces from the bar, had such a difference in structure, color, strength, and ductility, shows that the weakness of the bar, as tested by transverse stress, is not a necessary accompaniment of its composition, and it, no doubt, would have given much higher results if the whole bar had been cooled in exactly the same manner and subjected to the same pressure as the bottom of the bar.

In compiling the table of average results of torsion tests given above, the results of the tests of the pieces A, C, and D are rejected as defective, and the piece B is considered the only sound piece from the bar.

The curve plotted from this table (Plate III) then shows a regular increase from No. 1 to No. 7 (all copper to 80.95 copper, 18.84 tin), without any such break as it would have if the three pieces from the upper portion of bar No. 6 were admitted in the averages.

No 7, Plate XXXII (80.95 copper, 18.84 tin).—The piece from the lower end of the bar No. 7 B was found, upon testing, to contain a large cavity, similar to that in No. 5 B. The result of the test of this piece is therefore omitted from the averages. The other pieces, A, C, and D, were sound and gave good results, and agree with the transverse and tensile tests in showing the bar to be the strongest of the series, but as having very little ductility.

No. 8, Plate XXXII (76.64 copper, 23.24 tin).—The four pieces all gave good results. By inspection of the diagrams of these pieces, it will be observed that the elastic limit was not reached till fracture took place, as each diagram is nearly a straight line, slightly inclined from the vertical instead of being a curved line gradually approaching the horizontal, such as was given by all the more ductile pieces. These diagrams correspond with the curves plotted from the results of the transverse tests (Plate XVI), which also are nearly straight lines from the beginning of stress to the point of fracture, and fail to show an elastic limit, fracture apparently occurring before passing that limit. This composition, though somewhat hard and brittle, works very well in the lathe or planer.

The composition 75.00 copper, 25.00 tin is used by the Messrs. Perkins for the piston-rings of their high-pressure steam-engines without lubrication.

No. 9 to No. 17, Plates XXXII, XXXIII, XXXIV (29.89 to 57.30 tin) — The bars No. 9 to No. 17, inclusive, were so very hard that it was impossible to turn torsion pieces in the lathe to standard size without risk of breaking them. They were therefore only turned to cylindrical form, with diameters varying from 0.890 to 0.970 inch. Many of the pieces broke in the lathe even before the cylindrical form was reached, and thus, in many cases, only one or two pieces could be obtained from a bar. A few of the pieces, Nos. 9, 10, 11, and 12, could not be cut at all with the hardest steel tool, and were ground on a small emery wheel.

On account of the great lack of strength of these pieces, the 100-pound weight was removed from the arm of the machine, and the weight of the arm alone, or, in some cases with a 30-pound weight attached, was used to measure the resistance. The diagrams of strain of all these pieces are similar in character, being almost straight lines, very nearly vertical, and showing no elastic limit or point of change of direction of the line towards the horizontal.

The torsional moments of the pieces, whose diameters are larger than the standard size (0.625 inch), were reduced to the equivalent moments of pieces of standard size by dividing them by the ratio of the cubes of the diameters of the pieces to the cube of 0.625, since the resistances to rupture by torsion of pieces of different diameters vary as the cubes of the diameters. Thus reduced, the maximum torsional moments of these pieces range from 7.06 to 29.60 foot-pounds; or they were nearly from $\frac{1}{30}$ to $\frac{1}{7}$ as strong as the strongest piece tested, No. 7 C.

The resiliences, *i. e.*, the amounts of energy expended or work done in producing the rupture of these brittle pieces, are not reduced to the equivalents of pieces of standard size, since the relation between the diameters and resilience was undetermined. The figures of resilience which are given in the tables do not represent the moduli, but are the absolute resiliences of the pieces tested. The resilience reduced to a modulus for the standard diameter would be much smaller.

The enormous difference in resilience between these brittle specimens and those more ductile is seen, even without reducing them to a common standard.

The resiliences of the brittle pieces of large diameters vary from 0.19 to 0.92 foot-pounds, while that of No. 3 A, the most resilient piece of standard size, is 936.56 foot-pounds.

No. 18, Plate XXXIV (38.37 copper, 61.32 tin).—Three torsion pieces were obtained from this bar, of which two were turned to the standard size. The diagrams show the same distinguishing characteristics as those of Nos. 9 and 17, except that a slightly greater inclination from the vertical is to be noted, indicating less stiffness.

No. 19, Plate XXXIV (34.22 copper, 65.80 tin).—Three torsion pieces were tested which gave the characteristic diagrams of weak and brittle materials, but the piece marked B was nearly three times as strong as the pieces marked A and D. This is readily accounted for on examining the appearance of the fracture. It was coarsely granular, while the fractures of the pieces A and D were coarse and laminated or crystalline. This difference of structure does not appear to be due to a difference of composition, but it may be a consequence of a difference in the rate of cooling of the upper and lower ends of the bar, or of a difference in pressure in the liquid metal, such as has been observed in the notes on the test of No. 6 B.

No. 20, Plate XXXIV (25.85 copper, 73.80 tin).—Four pieces were tested, which exhibited the same differences in strength and in structure that were shown in No. 19. The piece A had a large prismatic crystalline or laminated structure, and the piece gave a torsional moment of only 10.84 foot-pounds. The piece C had a crystalline structure, but the crystals were very much smaller, were more confused and less well-defined. The torsional moment was 25.35 foot-pounds. The piece D was different from either, being rather open and granular and of a little darker color than either of the others. It was also very weak, giving a torsional moment of only 12.44 foot-pounds. The piece B again differed from all the others. It had a very close, fine, granular structure, and in color similar to those of A and C. There was a blow-hole in the center of the specimen, about ½ inch long and 0.15 inch in diameter, but notwithstanding the blow-hole it was much the strongest of any of the four pieces, having a torsional moment of 35.44 foot-pounds.

These differences in structure are not shown by the analyses to be due to liquation, as there is but little difference in composition of turnings from different portions of the bar, and similar appearances of color and structure are observed in pieces which are known to vary in composition as much as 10 per cent. In the grayish-white alloys the prismatic crystalline structure is usually found in the upper portion of the bar, and it is always accompanied by deficiency in strength. It is perhaps due to slow rate of cooling, or to lighter pressure than is sustained by the metal at the bottom of the mold.

No. 21, Plate XXXIV (23.35 copper, 76.29 tin) had a cavity *extending through its whole length* except five inches of the upper end. A torsion piece could only be obtained, therefore, from this upper portion. It exhibited a torsional resistance of 41.50 foot-pounds, which is greater than that of any piece from No. 9 (69.84 copper, 29.89 tin) to No. 29 (all tin). This gives a second maximum point of strength in the series, and one corresponding to those obtained by tensile and transverse stress. The structure was similar to that of the piece No. 20 B.

No. 22, Plate XXXIV (20.25 copper, 79.64 tin).—Four pieces were tested, showing resistances varying from 12.24 to 33.43 foot-pounds of torsional moment. The fractures were all confusedly crystalline, showing some differences in structure, which may account for their differences in strength. The strongest piece, No. 22 B, had an angle of torsion of 10 degrees, which is greater than that of any piece between No. 8 and No. 22, and marks the beginning of the ductile specimens at the latter end of the series. From No. 22 there is a regular increase of ductility to No. 29 (all tin), which is the most ductile of the series.

No. 23, Plate XXXV (15.08 copper, 84.62 tin).—Three pieces were tested, which gave diagrams nearly similar, the strength ranging from 20.31 to 26.36 foot-pounds, and the angles of torsion from 22 to 26.5 degrees. As shown by the diagrams, each piece twisted through several degrees after reaching its maximum resistance, the last portion of the diagram being a horizontal straight line. This appears to be a peculiarity of the more ductile white alloys. The yellow ductile metals do not usually reach their maximum resistances till nearly at the point of fracture.

No. 24, Plates XXXV, XXXVI (11.49 copper, 88.47 tin).—Four pieces were tested, giving torsional moments from 21.32 to 25.35 foot-pounds. Great differences in ductility were observed among these pieces, No. 24 A having an angle of torsion of 16 degrees and No. 24 C an angle of 109 degrees. There was nothing in the appearance of the fracture which would indicate the cause of these differences.

No. 25, Plates XXXVII, XXXVIII (8.57 copper, 91.39 tin).—Four pieces were tested, which gave diagrams nearly similar in shape. The pieces A, C, and D showed almost the same strength, viz, 21.32, 20.31, and 20.91 foot-pounds respectively, with corresponding angles of torsion of 153, 123, and 148 degrees. No. 25 B had much greater strength, viz, 29.39 foot-pounds, and a smaller angle of torsion, viz, 102 degrees. Its greater strength is partly accounted for by the method of test. As shown in the diagram, the speed of the handle of the machine was increased in the latter portion of the test, which at once caused an increased resistance, as shown by the rise of the diagram. This increase of resistance to rapid motion uniformly took place in all the white ductile alloys, and agrees with that which has already been noted under the transverse and tensile tests.*

No. 26, Plates XXXIX, XL (3.72 copper, 96 31 tin).—Four pieces were tested, but two are rejected from the table of averages on account of the existence of blow-holes, which were found in the center of the pieces after testing them. The remaining pieces B and D exhibited resistances of 19.30 and 26.36 foot-pounds, and gave angles of torsion of 251 and 190 degrees, respectively. The test of No. 26 D was purposely made rapidly, and its increased resistance is thus accounted for. The increase of resistance is apparently connected with a decrease of ductility in this piece as well as in No. 25 B, but in some other tests of ductile metals this did not always seem to be the case.

No. 27, Plates XLI, XLII, XLIII (0.74 copper, 99.02 tin).—Four pieces were tested, of which two, A and D, are rejected from the averages on account of blow-holes. The pieces B and C gave maximum torsional moments of 17.28 and 19.30 foot-pounds, with angles of torsion of 362 and 412 degrees, respectively. Referring to the diagram of No. 27 C, it will be seen that its maximum resistance took place only at a point where there was a rapid motion of the arm for an instant, and that at every other part of the diagram the resistance was less than that of No. 27 B, which was tested with a uniform slow motion. Although the ductility of No. 27 C is the greater, its resilience is less, which shows that it had a slower mean resistance. At different points of this test the rate of motion was changed, and at times stopped entirely. At one time the piece was left under stress for 16 hours, and at other times for the spaces of 10 minutes, 2 minutes, and 1 minute. At each of these rests the resistance of the piece decreased, as is shown by the fall of the diagram. A rise of the diagram is seen to take place whenever there is an increase in the rate of motion. This test exhibits in a very marked degree the influence upon the ductile metals both of rapid and slow distortion, and of decrease of resistance to static load when left for any length of time.†

No. 28, Plates XLIV, XLV, XLVI, XLVII (0.32 copper, 99.46 tin).—Four pieces were tested. The test of the piece A was made with the 100-pound weight on the arm of the machine, and consequently the ordinate of the diagram became so small that too great error in measurement may exist, and the test is therefore rejected from the averages. The other pieces were tested without the weight on the arm, with a uniform slow motion, and gave good results, showing considerable uniformity, both in strength and ductility.

No. 29, Plates XLVIII, XLIX, L, LI (all tin).—Four pieces were tested, the pieces A, B, and C with ordinary uniform slow motion, and the piece D with a much slower motion. The latter piece was also left under stress at different times for 40 and for 1, 2, and 4 hours. The first three pieces showed great uniformity, their diagrams being almost exactly similar. The latter, in consequence of the very slow motion, exerted a much smaller resistance, and, when left under stress, a decrease of resistance.

No. 30, Plates LII, LIII (all copper).—Four pieces were tested, all giving good diagrams. The torsional moments varied from 127 to 155 foot-pounds, and the angles of torsion from 105 to 177 degrees. All these tests show this bar of copper to be an excellent piece, confirming the results of the transverse and tensile tests. Comparing the results of the tests of the torsion pieces of No. 30 with those of the other copper piece, No. 1, a very great contrast is seen. The torsional moments of the latter were only 57 to 75 foot-pounds, and the angles of torsion only 26 to 49 degrees. The fractures of No. 30 were all compact and homogeneous, while those of No. 1 were all full of blow-holes.

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* See papers by the writer, Trans. Am. Soc. Civil Engrs., 1873–'76.

† See papers by the writer, &c.

TESTS BY COMPRESSION.

A number of pieces were taken from the broken tension-test specimens and turned into small cylinders to be tested by compressive stress. The size of these pieces was very accurately 2 inches in length and 0.625 inch in diameter. The ends were carefully made plane surfaces, perpendicular to the axis of the cylinder.

Nos. 1 D, 25, 26, 27, and 28, were tested in a compression attachment to the Rièhlé testing-machine (Fig. 6, p. 292), described in connection with the tensile tests, and the amounts of compression were measured by the apparatus (Fig. 13, p. 326) used in measuring tensile elongations in the second series. For these compression tests the level was removed, the arm which supported the level fixed, and a battery and signal connected to determine the point and instant of contact of the end of the micrometer-screw by the passage of a current of electricity.

All other tests were made on the testing-machine, of 100,000 pounds capacity, in use by the Ordnance Bureau, U. S. A., at the Army Building, New York City. In this machine the stress is applied by means of a lever operated by hand through a system of spur-gearing with a screw, and is measured by a combination of levers. A similar machine, designed by Major Wade, is described in a Report of Experiments on Metals for Cannon, by officers of the Ordnance Department, U. S. A., 1856.

On account of the small lengths of the specimens, it was difficult in this machine to make direct measurements of the amounts of compression. An approximation to the amounts was derived from noting the number of revolutions of the handle necessary to produce a certain compression.

It was found that 47¼ turns of the handle were required to cause one turn of the screw, which raised the main lever of the machine. The arms of the lever were as 10 to 1, and the pitch of the screw which elevated it was 0.4 inch. From these data it is found that one turn of the handle should produce a compression of the test specimen of 0.000846 inch.

From this is to be subtracted an error due to the spring or elasticity of the machine itself. A close approximation to the actual amount of this error was obtained as follows:

The piece No. 8 B was placed in the machine, and after a few hundred pounds pressure was applied for the purpose of taking up back-lash in the gearing, it required 296 turns of the handle to produce a stress of 32,000 pounds. At the same time the distance between the pressure-plates at the top and bottom of the piece, as measured by a scale divided to $\frac{1}{100}$ of an inch, was 1.83 inches, indicating an actual compression of the piece of 0.17 inch. The calculated compression, including the error, was 296 turns × 0.000846=0.250416 inch. The error is, therefore, 0.250416—0.17=0.080416 inch.

We may safely assume that the error due to the elasticity of the parts of the machine is proportional to the stress, and hence $\frac{0.080416}{32000}=$

0.0000025 is the error of the calculated compressions for each pound of stress.

This comparison of calculated with actual compressions was repeated a great number of times with nearly similar results, and the averages of the most reliable observations gave the same figure.

Table No. V, giving the results of all the tests by compressive stress, is appended. The figures given in the table as the compression of the pieces tested in the testing-machine of the Ordnance Bureau were calculated from the number of turns of the handle required to produce the corresponding stress, in the manner above stated, using the formula

$$C = 0.000846\ N - 0.0000025\ P$$

where C is the amount of compression in inches, N the number of turns of the handle, and P the applied stress in pounds.

The following table, V, presents a condensed summary of the results of these experiments. The results are also combined with those of the second series in the plotted curves of Plate IV.

TABLE V.—TESTS BY COMPRESSIVE STRESS.

First Series.—Alloys of Copper and Tin.

No.	Composition by analysis.		Load per square inch causing a compression of—			Maximum load per sq. inch.	Total compression produced by maximum load. Parts of original length.	Crushing strength per square inch.	Remarks.
	Copper.	Tin.	5 per cent.	10 per cent.	20 per cent.				
			Pounds.	*Pounds.*	*Pounds.*	*Pounds.*		*Pounds.*	
1	Cast copper.		26,000	39,000	51,000	74,968	.4480	39,000	Flattened.
1 D	do		33,000	45,500	58,671	78,228	.4339	45,500	Do.
2	97.83	1.92	29,335	34,000	46,000	46,263	.3680	34,000	Do.
3	95.96	3.80	39,200	42,048	52,152	52,152	.3025	42,048	Do.
4	92.07	7.76	31,500	42,000	65,000	84,095	.4535	42,000	Do.
5	90.43	9.50	32,000	38,000	60,000	61,930	.3355	38,000	Do.
6	87.15	12.77	39,000	53,000	80,000	89,636	.3860	53,000	Do.
7	80.99	18.92	65,000	78,000	103,489	103,489	.2030	78,000	Do.
8	76.60	23.23	101,044	....	....	114,081	.0905	114,081	Crushed.
9	69.90	29.85	....	....	....	146,676	.0350	146,676	Do.
11	65.31	34.47	....	....	....	84,747	.0285	84,747	Do.
12	61.63	37.74	....	....	....	39,114	.0175	39,114	Do.
15	47.72	51.99	....	....	....	84,747	.0215	84,747	Do.
16	44.62	55.15	....	....	....	35,854	.0066	35,854	Do.
17	38.83	60.79	....	....	....	39,114	.0205	39,114	Do.
18	38.37	61.32	....	....	....	29,335	.0145	29,335	Do.
19	34.22	65.80	19,557	....	....	19,557	.0555	19,557	Do.
20	25.12	74.51	17,927	17,927	17,927	17,927	.2805	17,927	Do.
22	20.21	79.62	16,297	16,297	16,297	16,297	.2905	16,297	Do.
23	15.12	84.58	6,519	6,519	6,519	9,452	.5135	6,519	Flattened.
24	11.48	88.50	10,104	10,104	10,104	14,016	.5040	10,104	Do.
25	8.57	91.39	6,500	....	....	9,778	.0558	9,778	Do.
26	3.72	96.31	6,519	6,519	6,519	9,778	.3422	9,778	Do.
27	0.74	99.02	6,519	6,519	6,519	9,778	.3632	9,778	Do.
28	0.32	99.46	6,519	6,519	6,519	9,778	.3760	9,778	Do.
29	Cast tin.		6,030	6,400	6,519	7,497	.4445	6,400	Do.
30	Cast copper.		34,000	42,000	58,000	71,709	.3210	42,000	Do.

NOTES ON THE TESTS BY COMPRESSION.

The more ductile alloys, No. 1 to No. 7 (all copper to 80.95 copper, 18.84 tin), and No 23 (15.08 copper, 84.62 tin) to No. 30 (all copper), were not crushed or broken by any stress which could be applied to them, but either bent after sustaining a certain degree of compression, or retaining a vertical position, increased in diameter as the decrease in length took place, and gradually flattened. Some of the pieces were in this manner compressed to less that one-half of their original lengths, the resistance to further compression always increasing. When the bending took place, the piece under compression would, in some cases, take such a position as to gradually diminish in resistance to stress, the pressure-plates touching only on the edges of the upper and lower surfaces of the piece.

The actual "crushing strengths" of the ductile metals, therefore, cannot be stated; but for purposes of comparison the crushing strength is assumed to be that which corresponds to a compression of one-tenth of the original length. In the above table, therefore, the figures in the column headed "crushing strength" represent, in the cases of ductile metals, the loads per square inch necessary to produce compressions of 10 per cent. of the original lengths.

All the brittle alloys, and some of those possessing certain limited amounts of ductility, No. 8 (76.64 copper, 23.24 tin) to No. 18 (38.37 copper, 61.32 tin) inclusive, broke suddenly when their maximum resistances were reached, and the figures for their crushing strengths are, therefore, the actual values. In these, the figures for "total compression produced by maximum load" are the calculated compressions at the instants of the sudden breaking. In the cases of the others, the figures in the same columns are the total compressions which were actually given to the pieces without breaking them, and include the shortening of the piece by bending, but are not the total amounts of compression which might have been produced if the test had been continued further.

The loads per square inch, producing compressions of 5 per cent. and 20 per cent., are also given in the table for purposes of comparison.

By inspection of the table and the curves (Plates IV, VII), and comparing the results with those of the transverse, tensile, and torsional stresses, some important facts are observed. Assuming, as already stated, that the crushing strength of a ductile metal is the load necessary to produce a compression of one-tenth of the original length, and that of a brittle metal is the load actually causing fracture, it is seen that the maximum and minimum compressive strengths are not found in the compositions which exhibited maximum and minimum strengths by the other three methods of tests. It has already been observed that the relative strengths of the various alloys, as shown by the other three methods of tests, are similar. This is not the case with the compressive tests.

The maximum crushing strength is given by No. 9 (69.84 copper, 29.89 tin), which gave results much nearer the minimum under the other forms of test. The minimum crushing strength is found in tin, which was superior to several of the brittle alloys in other methods of tests, and which alloys greatly surpassed it in tests by compression. It appears that the resistance to compression has an entirely different nature from resistance to tension, and that the tin qualities have no apparent relation to each other.

The compression pieces, No. 1 (all copper) to No. 5 (90.27 copper, 9.58 tin), and No. 30 (all copper), give results very nearly alike, varying from 34,000 to 42,000 pounds per square inch to produce a compression of one-tenth of the original length. From No. 6 (87.15 copper, 18.84 tin) to No. 9 (69.84 copper, 29.89 tin) there is a rapid increase up to 146,676 pounds per square inch. From this point a decrease takes place to No. 29 (all tin). This decrease is somewhat irregular, No. 11 (65.34 copper, 34.47 tin) and No. 15 (47.61 copper, 52.14 tin) giving a crushing strength of 84,747, and No. 12 (62.31 copper, 37.35 tin) only 39,114 pounds. It would be necessary to make a greater number of tests before attempting to explain this irregularity, but it does not seem improbable that it may be a peculiarity of these compositions, since No. 12 was very different in color from both No. 11 and No. 15, and had the highest density of the series, a density much higher than that of No. 15. It may be that an alloy of nearly the composition of No. 12 represents a *second minimum* point of compressive strength in the curve, and an alloy near No. 15 may give a *second maximum* point, as No. 21 (23.35 copper, 76.29 tin) gave a second maximum by the other tests and No. 29 (all tin) a second minimum. It will require further tests, however, to settle this point definitely.

The following phenomena were observed in connection with these tests in addition to those noted in the tables. The behavior of the test-pieces is clearly shown in the plotted curves, Plate XX.

No. 1 (all copper).—This piece had a few small blow-holes on the turned surface, but appeared to be sounder than most of the bar from which it was taken. It was noticed to have taken a scarcely perceptible bend when a stress of 29,000 pounds per square inch was reached after a compression of 6.4 per cent. As the stress increased the bending became more readily observable, and when the piece was removed, after a compression of 44.8 per cent., it was very considerable. The piece had then become much distorted, the bend taking a special direction, and the diameter had increased to about 0.77 inch, varying slightly in different portions of the length. The amount of compression began to vary more rapidly than the stress, after a stress of 13,000 pounds per square inch had been applied, showing apparently an elastic limit. It is probable, however, that this point does not truly represent the limit of elasticity, but was the point at which the bending commenced, although its effect was not perceptible till a much higher stress had been applied, and that, beyond this point, the figures under the column headed "compression" really represent a shortening of the vertical distance between the ends of the specimen by the combined action of bending and compressive stresses.

No. 1 D (cast copper).—A second specimen, taken from the D end of the bar, was subsequently tested in the compression testing machine. The results as plotted show a curve similar to that of the one just noted, but the resistances to compression are uniformly higher. The maximum compression obtained was 0.8678 inch under a pressure of 78,228 pounds per square inch. A pressure of 81,487 pounds per square inch was next applied, which broke the specimen into three parts. Wedge-shaped pieces, with bases the full diameter of the test-piece, separated at top and bottom, the planes of separation inclining and meeting at the middle of one side. The three pieces remained welded together by the pressure.

No. 2 (97.83 copper, 1.92 tin).—The amount of compression was nearly proportional to the stress up to about 25,000 pounds per square inch. At 29,000 pounds per square inch the bending of the piece became perceptible, and at that point a continuance of the stress for about one minute produced an evident increase of the compression. From 29,000 to 46,000 pounds the compression again varied nearly as the stress, but the ratio of compression to stress was much greater than in the beginning of the test. At 46,000 pounds the piece had a marked double curvature in one plane, and appeared to slide on the pressure-plates, so that the pressure was applied only on opposite edges of the upper and lower surfaces of the specimen instead of evenly over the whole surface. After this point the resistance rapidly decreased, not from any giving way of any fibers of the material, but from the specimen taking a position which was unfavorable to resistance to stress, and bending then took place rapidly without any further compression. The resistance fell to 6,000 pounds per square inch, when the piece finally only touched the pressure plates with the edges of its upper and lower surfaces. The diameter of the specimen when removed had increased to 0.71 inch.

In the plotted table of curves (Plate XX) the curve of this specimen is seen to attain its maximum ordinate at 46,000 pounds per square inch, and after that point to rapidly approach the axis of abscissas. It is to be noted in all these tables and curves which show a decrease of resistance after reaching a maximum that this decrease is due to the bending of the specimen and not to decrease of power to resist actual compression.

No. 3 (95.96 copper, 3.80 tin).—The action of this piece under test was similar to that of No. 2. The compression was proportional to the stress up to 32,000 pounds per square inch. Bending first became perceptible at 40,000 pounds, and soon afterwards a decrease of resistance took place. The piece then seemed, for a short time, to attain a position in which it could offer greater resistance to increased stress, and the maximum was reached at 52,000 pounds. The resistance then decreased rapidly till the piece was removed. Its axis became a line of double curvature like that of No. 2, and the piece finally touched the pressure-plates only with the edges of its upper and lower surfaces. When removed the diameter was found to have increased to 0.68 inch.

No. 4 (92.07 copper, 7.76 tin).—This piece bent under stress with a double curve similar to that of No. 3. The *apparent* elastic limit was reached at 26,000 pounds, and bending was first observed at 29,000 pounds; the maximum resistance was reached at 84,000 pounds, after which it rapidly decreased by reason of the bending. When removed, the diameter was found to be increased to 0.73 inch.

No. 5 (90.43 copper, 9.50 tin).—The compression was proportional to the stresses only to 20,000 pounds per square inch, but bending was not observed until 32,000 pounds had been reached. The bending took place in one plane, giving a double curvature, and increased rapidly, so that the maximum resistance was reached at 61,930 pounds per square inch. The resistance then decreased rapidly to 13,000 pounds, when the piece had taken such a position that it ceased to resist further compression, and slipped out from between the plates. The diameter was found to have increased to 0.69 inch.

No. 6 (87.15 copper, 12.77 tin).—This piece was taken from the bottom of the bar, where the metal was found by the torsion tests to be the most homogeneous. The piece bent in the same manner as those described above, but in addition to the bending, the surface of the piece became curiously distorted, as if small patches of the surface were softer than other portions, and these resisted compression less than the harder portions. The compression was proportional to the stress to about 30,000 pounds per square inch. Bending was first observed at 35,000 pounds, after which the further compressions were again proportional to the stresses, the ratio of compression to stress being greater than in the first part of the test. The maximum resistance was reached at 89,000 pounds per square inch, after which the resistance decreased, by reason of the bending, to 32,000 pounds, when the piece slipped out from between the pressure-plates. The diameter was increased to 0.70 and 0.73 inch as measured in different portions of the length.

No. 7 (80.99 copper, 18.92 tin).—The compression remained nearly proportional to the stress up to about 60,000 pounds per square inch. A very slight bending was observed at about 67,000 pounds, the piece taking a double curve in one plane. The maximum resistance was reached at 103,500 pounds per square inch, after which it decreased to 91,000 pounds. A crack then appeared on each of the two convex surfaces of the double curve, and the piece slipped out from between the pressure-plates, at the same time crushing off small pieces of the metal at the edges of the upper and lower surfaces, which last touched the pressure-plates. The diameter was increased to 0.67 inch.

No. 8 (76 60 copper, 23.23 tin).—The compression was proportional to the stress to about 91,000 pounds per square inch, after which the ratio of the former to the latter slightly increased. A very slight bend was observed at 107,000 pounds. The maximum pressure was reached at 114,000 pounds, when the piece suddenly broke diagonally across the middle, after a total compression of 9.05 per cent. In breaking, the diagonal surfaces slipped on one another in such a manner that they became polished. The diameter was uniformly increased to 0.64 inch.

No. 9 (69.90 copper, 29.85 tin).—This piece proved to be the strongest of the series, a stress of 146,676 pounds per square inch being required to produce rupture. The compression remained nearly proportional to the stress throughout the whole test. There was no appearance of bending, and the fracture took place without any warning whatever. The piece suddenly broke into an immense number of small pieces, the largest of which was not larger than a pea. A report like a pistol-shot was made as the piece broke. The record of the test shows a calculated compression of 3.50 per cent. From the nature of the material it seems possible that this figure may be too high.

No. 11 (65.31 copper, 34.47 tin).—The compressions were nearly proportional to the stresses throughout the test. The piece broke suddenly at 84,747 pounds per square inch, the upper portion of the piece flying into fragments.

No. 12 (61.83 copper, 37.74 tin).—This piece broke nearly in the same manner as No. 11, but sustained less than one-half the amount of stress—39,000 pounds.

Nos. 10, 13, and 14 were not tested, as they broke in the lathe while being turned.

No. 15 (47.72 copper, 51.99 tin).—This piece gave the same result as No. 11, breaking at 84,747 pounds per square inch. It broke suddenly into several large fragments.

No. 16 (44.62 copper, 55.15 tin).—This piece sustained a stress of only 35,854 pounds per square inch. The fracture took place suddenly, and it appeared as if in the upper end of the specimen a cone-shaped wedge was formed, which split open the metal on all sides, and produced a vertical crack through the center of the piece, reaching to the bottom.

No. 17 (38.83 copper, 60.79 tin).—Two pieces were tested from this bar, which gave similar results, breaking at 39,000 pounds per square inch. The fractures were of the same character as that of No. 16.

No. 18 (38.37 copper, 61.32 tin).—This specimen proved to be much weaker than any previously tested, breaking at 29,000 pounds per square inch. It broke by wedge-shaped fragments flying off the upper end. The compression was proportional to the stress up to the breaking point.

No. 19 (34.22 copper, 65.80 tin).—This piece was even weaker than No. 18. It reached a maximum resistance at 19,500 pounds per square inch after a compression of 1.20 per cent., the compression being proportional to the stress at this point. The resistance to stress then decreased rapidly, the piece bulging out on all sides about a diagonal plane of fracture near the middle. Several cracks soon appeared around the point of bulging, and the resistance decreased to 8,800 pounds per square inch, when the piece was removed. The total compression was 5.55 per cent. The diameters of the ends of the specimens, which were apparently not affected by the bulging in the middle of the piece, had increased to 0.630 inch.

No. 20 (25.12 copper, 74.51 tin).—This piece reached a maximum resistance at 17,900 pounds per square inch, the compression being nearly proportional to the stress, after which it rapidly decreased to 2,900 pounds. During this decrease a remarkable phenomenon was observed. A diagonal crack appeared at the top of the specimen, reaching from one edge of the upper surface to a point on the cylindrical surface opposite to this edge, and about ¾ inch from the top. The wedge-shaped piece thus fractured from the specimen was gradually forced along the line of fracture till it was nearly pushed off on one side, but still remained attached, as if by "cold welding." When this partly separated piece first started off from the remainder of the specimen, the larger part of the stress appeared to be resisted by only a small portion of the upper surface, and the resistance consequently decreased to 2,900 pounds per square inch. This portion of the upper surface was then gradually flattened, and so apparently better fitted to resist a further amount of compression. As the compression increased from 6.80 to 25.60 per cent. the resistance again increased from 2,900 to 10,267 pounds. By this time a second but much smaller wedge had been forced off on the side opposite the larger one, and the action above described was repeated. A large number of still smaller wedge-shaped pieces were then partially detached and surrounded the whole of the upper end of the specimen. After reaching the second maximum, 10,267 pounds, the resistance began to decrease again, but the specimen was removed after a compression of 28.05 per cent. with the first wedge-shaped piece still attached to its upper end. The diameter of the lower portion of the specimen had increased only to 0.629 inch when it was removed. Fig. 11 shows the appearance of this specimen after its removal.

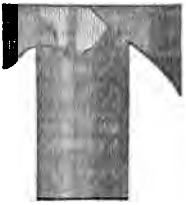

Fig. 11.

No. 22 (20.21 copper, 79.62 tin).—The compression continued nearly proportional to the stress to about 12,000 pounds per square inch. At about 16,000 pounds a bend in the specimen was observed, and at the same time the resistance to stress decreased, as further compression took place, to 7,000 pounds. The resistance afterward increased to 10,400 pounds per square inch, by reason, probably, of the piece taking a more favorable position to resist bending, and then it again decreased to 1,300 pounds, when the piece had bent so much that it slipped out from between the pressure-plates. The bend took the shape of a double curve in one plane, and a crack appeared on each of the two convex surfaces of the curve in like manner as in No. 7. The diameter of the piece was increased to 0.65 inch.

No. 23 (15.12 copper, 84.58 tin).—This piece behaved in a manner somewhat similar to No. 20. The compression continued nearly proportional to the stress till 6,500 pounds was reached. The resistance then decreased to 4,563 pounds. At the same time a slight bulging took place about half an inch from the bottom. The bulging increased, and the upper portion of the piece apparently crushed out the lower portion, which latter still remained attached to the specimen, as did the wedge-shaped pieces in No. 20. As the compression proceeded the portion of the piece above the bulging appeared to obtain a better bearing, and after the resistance had decreased from 6,519 to 4,563 pounds, it again increased gradually to 9,452 pounds, the piece being then compressed more than one-half of its original length. The shortening of the piece took place almost entirely by crushing out portions at the lower end, and these portions remained attached to the piece, by what has been termed a sort of "cold-welding," till they were separated by other pieces crowding them off. The diameter of the upper end of the specimen was increased only to 0.645 inch (original diameter 0.625 inch).

No. 24 (11.48 copper, 88.30 tin).—This piece attained a resistance of 10,104 pounds per square inch with a compression of 6.94 per cent., when a slight double curve was observed and the resistance decreased very slightly. As the compression was continued, the diameter of the piece gradually increased throughout the whole length, and the resistance increased to 14,000 pounds per square inch, when the piece had been compressed more than one-half of its original length. There were no signs of any fracture, and the piece merely flattened out, offering continually greater resistance. The compression could probably have been continued till the piece flattened out to a thin sheet, if the limits of the machine had allowed. When removed, the piece was somewhat irregular in shape, the diameters varying from 0.85 to 0.88 inch.

No. 25 (8.57 copper, 91.39 tin).—A pressure of 65.9 pounds per square inch compressed the specimen 0.1117 inch. The load was increased to 9,778 pounds per square inch, the effect of which was to crack the specimen at top and bottom, forming wedge-shaped pieces, which, however, did not become separated from the mass. The height of the specimen when removed from the machine was 1.06 inches. The section was very irregular, somewhat elliptical in form, and varying in diameter from 0.84 to 0.95 inch.

No. 26 (3.72 copper, 96.31 tin) yielded gradually to the applied stress. At a pressure of 6,519 pounds per square inch the compression was 0.6845 inch; the pressure was increased to 9,778 pounds per square inch and the piece was then removed. Its height had been diminished to 1.01 inches. Its diameter varied from 0.84 to 0.89 inch. The shape of the specimen when removed from the machine was oval. The wrinkled appearance of the sides extending throughout the height of the test-piece was an evidence of the homogeneousness of the alloy. The piece was considerably bent; the directions of the markings or lines showed a tendency to a wedge-shaped separation at the top and bottom. The ductility of the piece, however, was too great to permit fracture even under such an amount of compression.

No. 27 (0.74 copper, 99.02 tin) offered a somewhat less resistance to compression than No. 26. A pressure of 6,519 pounds per square inch compressed the piece 0.7264 inch. The pressure was increased to 9,778 pounds per square inch, and the piece then removed. Its height was reduced to 0.95 inch, and its section, which was elliptical though irregular, varied from 0.84 to 0.95 inch. The appearance of the piece was dissimilar to both Nos. 26 and 28, the sides being quite smooth instead of being wrinkled all over its surface, as was the case with the other two.

No. 28 (0.32 copper, 99.46 tin) resembled No. 26 very closely in behavior and appearance. The surface, was more uniformly wrinkled, showing greater uniformity of resistance to the applied stress. No crack appeared. The compression under a pressure of 6,519 pounds per square inch was 0.752 inch. Under a pressure of 9,778 pounds per square inch the height of the piece was reduced to 0.98 inch. Its section was slightly oval, with diameters averaging from 0.87 to 0.89 inch.

No. 29 (all tin) behaved in all respects like No. 24, showing a gradually increasing resistance until the piece was removed with a compression of nearly one-half its original length. The maximum resistance, however, was much less than that of No. 24, being only 7,497 pounds per square inch. The diameters of the piece after removal varied from 0.85 to 0.89 inch, and had a nearly elliptical section.

No. 30 (all copper).—The compression continued nearly proportional to the stress up to about 25,000 pounds per square inch. A very slight bend in a double curve was then observed. The resistance increased to 71,709 pounds per square inch at a compression of 32.1 per cent., when the piece was removed, its diameters having increased to 0.75 and 0.78 inch as measured in various parts of its length. The bend in the piece was but slight, and it would apparently have offered increased resistance to further compression indefinitely.

SECOND SERIES.

ALLOYS OF COPPER AND TIN.

The second series of copper and tin alloys consisted of twenty bars cast in the same manner as those of the preceding series. The mixtures were made without reference to the chemical equivalents or the atomic weights of the metals, but were weighed in even percentages, there being a constant difference of 5 per cent. between any two adjoining bars in the series. The first bar contained in the original mixture 97.5 per cent. copper and 2.5 per cent. tin; the second, 92.5 copper and 7.5 tin, and so on to the twentieth bar, which contained 2.5 per cent. copper and 97.5 per cent. tin. The bars were numbered in regular order from No. 31 to No. 50.

The following table shows the percentage composition of the original mixture of each bar, its mean composition as subsequently determined by analysis of turnings from different portions of the bar, and its mean specific gravity:

TABLE VI.—SECOND SERIES—ALLOYS OF COPPER AND TIN.

Composition by Original Mixture and Analysis.

Number.	Composition of original mixture.		Mean composition by analysis.		Mean specific gravity.
	Copper.	Tin.	Copper.	Tin.	
31	97.5	2.5	99.09	0.87	....
32	92.5	7.5	94.10	5.43	8.684
33	87.5	12.5	88.40	11.59	8.647
34	82.5	17.5	82.72	17.33	8.792
35	77.5	22.5	77.56	22.25	8.917
36*	72.5	27.5	72.89	26.85	8.925
37	67.5	32.5	67.87	32.09	8.907
38	62.5	37.5	62.42	37.48	8.956
39	57.5	42.5	57.87	42.05	8.751
40	52.5	47.5	53.46	46.54	8.643
41	47.5	52.5	47.27	52.72	8.445
42	42.5	57.5	43.99	55.91	8.437
43	37.5	62.5	37.10	62.90	8.101
44	32.5	67.5	30.76	69.19	7.391
45	27.5	72.5	26.62	73.18	7.915
46	22.5	77.5	22.10	77.58	7.774
47	17.5	82.5	16.70	83.23	7.690
48	12.5	87.5	11.68	88.25	7.542
49	7.5	92.5	6.05	93.77	7.419
50	2.5	97.5	2.11	97.68	7.842

* Second casting; first broke in emery planer.

The mixtures for these alloys were carefully weighed on the balance used in weighing out the first series, and the melting and casting were conducted in the same manner. The cast-iron mold was used for all the bars, placed in a vertical position, and was heated to prevent sudden chilling of the molten metal while being poured. The mold was heated to nearly red heat in casting the alloys containing the larger percentages of copper, and the temperature was diminished as the percentage of tin increased.

Much less difficulty was experienced in getting good castings at the first melting than in the first series. Bars No. 32 (94.10 copper, 5.43 tin) and No. 37 (67.87 copper, 32.09 tin) only requiring to be melted three times, and all the others only once. Bars No. 38 (62.42 copper, 37.48 tin) to No. 42 (43.99 copper, 55.91 tin) inclusive, however, broke either in the mold while cooling, or on being taken from it, or in subsequent handling. In these cases tests were made of the broken pieces without remelting. The difficulty with No. 32 and No. 37 appeared to be caused by pouring the metal in the first meltings at too low a temperature.

In casting bars No. 37 (67.87 copper, 32.09 tin) and No. 39 (57.87 copper, 42.05 tin) a curious phenomenon was observed. After filling the mold with the molten metal a small amount was still left in the bottom of the crucible. This was poured out on the brick floor of the foundry and left to cool. While cooling, the surface of the metal became covered with an aggregation of grayish-colored needle like crystals, which appeared to *grow* out of the metal and cover it in some places nearly to the depth of one-fourth of an inch. The crystals were removed from the metal and handed to Prof. A. R. Leeds, of the Stevens Institute of Technology, for examination, who made a report in which he calls the substance an artificial mineral. He says concerning it:

> The crystals are needles, not exceeding $\frac{1}{4}$ inch in length and $\frac{1}{250}$ inch in thickness. Luster adamantine and of great brilliancy. Color, white and transparent. It scratched glass, its hardness being over 6. The specific gravity at 62° Fahr., by the bottle, is 6.019. It will be noted that this is lower than the specific gravity of natural cassiterites which is from 6.4 to 7.1. It glows brilliantly in the oxidizing flame, but gives no evidence of fusion at the terminations of the crystal. It tinges the flame green. With soda it gives a white coating of oxide of tin. Crystals apparently not affected by several hours' digestion in hydrochloric and nitric acids.
>
> In chemical constitution it is a stannic oxide, containing a small amount of oxide of copper. The mineral is therefore an artificial variety of crystallized stannic oxide or cassiterite.

As the temperature of the metal while being poured is supposed to have some influence upon its properties, an attempt was made to obtain the temperatures of casting with this series of alloys by pouring a small portion of the molten metal, just before pouring the remainder into the mold, into a certain weight of water contained in a wooden vessel and noting the increase of temperature of the water caused by the hot metal, and also the weight of the metal poured. This method is the same as that employed by Messrs. Levi and Kunzel in their experiments on phosphor-bronze.*

The data obtained are the weight of the water used, its temperatures before and after pouring the metal into it, and the weight of the metal. The relative temperature is then found from the formula

$$x = \frac{P^1 (t^1 - t)}{P c} + t^1$$

in which P^1 is the weight of the water, P, the weight of metal poured, t the temperature of the water before and t^1 the temperature after pouring, and c the specific heat of the alloy.

The specific heat of the alloy is assumed to be the mean of the specific heats of the component metals, and for these the figures of Regnault are used, viz, copper 0.09515, tin 0.05623.

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* *Comptes Rendus*, Vol. 73, 1871, pp. 530–534.

This formula will not give the actual temperature of casting, since it neglects the fact that the specific heat of a melted metal may not be the same as that of the solid metal, and since also it neglects the latent heat of fusion of the melted metal, the amount of which is, as yet, unknown. The results, however, will approximately and relatively represent the temperatures, and as the data are all given below, the actual temperatures may be calculated whenever the specific heats of the molten alloys and their latent heats of fusion shall have been determined. The amount of heat transferred to the wooden vessel which contained the water, was not determined, but the loss is probably so slight that it may be neglected without material influence upon the result. The following table gives the data which were obtained in these experiments, and the temperatures calculated from them:

TABLE VII.—SECOND SERIES—ALLOYS OF COPPER AND TIN.

Estimated temperatures of Casting.

Number.	Composition by original mixtures.		Weight of water.	Weight of metal.	Temperatures of water, centigrade scale.			Assumed specific heat.	Calculated relative temperature.	
	Copper.	Tin.			Initial.	Final.	Range.		Centigrade.	Fahrenheit.
			Gram.	*Gram.*						
31.......	97.5	2.5	907	74	8.3	22.8	14.5	0.094177	1909.9	3469.8
32.......	92.5	7.5	907	101	12.8	31.7	18.9	0.092231	1871.9	3401.4
33	87.5	12.5	907	149	16.7	42.8	26.1	0.090285	1802.6	3276.6
34.......	82.5	17.5	907	362	9.4	60.0	50.6	0.088339	1495.1	2723.0
35.......	77.5	22.5	907	225	15.0	47.3	32.3	0.086393	1554.5	2829.2
36.......	72.5	27.5	907	157	11.7	33.3	21.6	0.084447	1511.8	2751.8
37.......	67.5	32.5	907	97	11.1	26.1	15.0	0.082501	1726.2	3148.8
38.......	62.2	37.5	907	177	10.6	31.7	21.1	0.080555	1373.9	2503.4
39.......	57.5	42.5	907	129	17.2	32.8	15.6	0.078609	1428.0	2602.4
40.......	52.5	47.5	907	214	8.3	35.0	26.7	0.076663	1511.1	2751.8
41.......	47.5	52.2	907	216	12.2	50.5	38.3	0.074717	2205.0	4001.0
42.......	42.5	57.5	907	328	9.5	47.2	37.8	0.072771	1063.8	1945.4
43.......	37.5	62.5	907	293	13.9	38.9	25.0	0.070825	1131.7	2067.8
44.......	32.5	67.4	907	255	8.9	32.2	23.3	0.068879	1756.9	3192.8
45.......	27.5	72.5	907	85	7.8	18.3	10.5	0.066933	1701.6	3093.8
46.......	22.5	77.5	907	277	12.2	38.9	26.7	0.064987	1382.7	2519.6
47.......	17.5	82.5	907	241	15.5	37.2	21.7	0.063041	1331.1	2427.8
48.......	12.5	87.5	907	104	14.4	22.7	8.3	0.061095	1211.9	2211.8
49.......	7.5	92.5	907	240	18.9	33.3	14.4	0.059149	956.5	1752.8
50	2.5	7.5	907	153	20.5	27.2	6.7	0.057203	725.3	1337.0

The temperatures of casting of bars No. 32 and No. 37 given above, are those of the third casting, those of the first and second meltings being of no value, as the third casting only was used in the tests.

In the first casting of bar No. 32 (94.10 copper, 5.43 tin), while pouring of the metal into the water for the temperature test, an explosion took place which broke the wooden vessel which held the water, and threw water and metal about with great violence. It appears probable that the metal was heated to an unusually high temperature, as in pouring other metals when at a dazzling white heat explosions sometimes took place, but they were usually not violent enough to do more than make a slight report as the hot metal touched the water.

After the bars were cast they were finished to a rectangular section by grinding on an emery-wheel planing-machine. The brittle alloys gave a great deal of trouble by breaking at the ends, and some of them in the middle, while being ground.

Bar No. 37 (68.87 copper, 32.09 tin) showed a most remarkable degree of brittleness. When cast it appeared perfectly sound, and was taken out of the mold and laid upon the table while still hot. While cooling, a chip of about half an inch long flew off from each of two of the bottom corners of the bars. The fracture had a curved surface, and left the bottom corners rounded. The next day an attempt was made to grind the top of the bar on an emery wheel. Chips of similar curved form instantly flew off from the corners, and on continuing to press the end of the bar against the side of the wheel, resting it at the same time on a table which almost touched the wheel, chips continued to fly from the bar, always breaking with a curved or conchoidal fracture. Finally several chips flew off at once, and left the end of the bar with a rounded point, brilliant and smooth, as if the metal had been melted off. It was then attempted to grind the lower end on a grindstone, but the attempt only succeeded after several chips were broken off, although the greatest care was used in holding it against the stone. The appearance of this bar was almost exactly similar to that of No. 10 (68.58 copper, 31.26 tin) in the first series, which had nearly the same composition.

Bar No. 38 (62.42 copper, 37.48 tin) broke into three pieces while being ground, and the two fractured surfaces showed that liquation had taken place, which was subsequently confirmed by analysis. The upper fracture, 9 inches from the top of the bar was smooth, conchoidal, and brilliant silver-white in color, like bar No. 37 (67.87 copper, 32.09 tin), while the fracture at the lower part of the bar, 5 inches from the bottom, was dark gray, radiated and crystalline, so different from the first that it indicates an entirely different character of metal. Fractures produced during the tests showed that the change from one appearance to the other was gradual, and that there was apparently a gradual increase in the percentage of copper in the bar from bottom to top. This phenomenon resembles that shown by bars No. 14 (51.62 copper, 48.09 tin) and No. 17 (42.38 copper, 57.30 tin) of the first series, both of which contained less copper than No. 38.

No. 39 (57.87 copper, 42.05 tin) and No. 40 (53.46 copper, 46.54 tin) also broke in handling, but did not exhibit any appearance of liquation. The fractures of No. 39 were all similar to that of the lower part of No. 38.

TESTS BY TRANSVERSE STRESS.

Second Series.—Alloys of Copper and Tin.

The bars, after having been prepared by grinding, were then tested by transverse stress.

The apparatus used was the testing machine of the Mechanical Laboratory of the Stevens Institute of Technology mentioned on page 291 as having been used in the tests of bar No. 30. A cut of this machine is shown below.

The apparatus consists of a combination platform-scale of 4,000 pounds capacity, having a platform 5 feet in length and 3½ feet in width, carrying a heavy cast-iron base-plate, C, 5 feet long, on which are mounted two heavy standards or supports, D D, twelve inches high, which slide along in a groove in the base-plate C, and may be clamped at any point. These supports are level on their upper surfaces, and carry two rollers, upon which the bar to be tested is supported. The pressure is exerted by means of a hand-wheel, K, turning a large square-threaded screw, which works in a large nut supported by two bolts, F F, which pass down to and are secured by large washers and nuts to a heavy oak crossbeam, G, underneath. The stresses thrown on the bar by the hand-wheel and screw are resisted directly by the platform of the scale, and are registered on the scale-beam M, which is graduated to read to two pounds, but is sensitive to less than half a pound. To insure more accurate balancing, a pointer was attached to the end of the scale-beam, which moves across a graduated arc. The pointer was always brought to rest at the middle of the arc in taking the observations. The apparatus has worked very satisfactorily and gives results with much greater rapidity, and with equal, if not greater, correctness than the machines used in testing the first series, in which weights were required to be lifted on and off the bar whenever a set was observed.

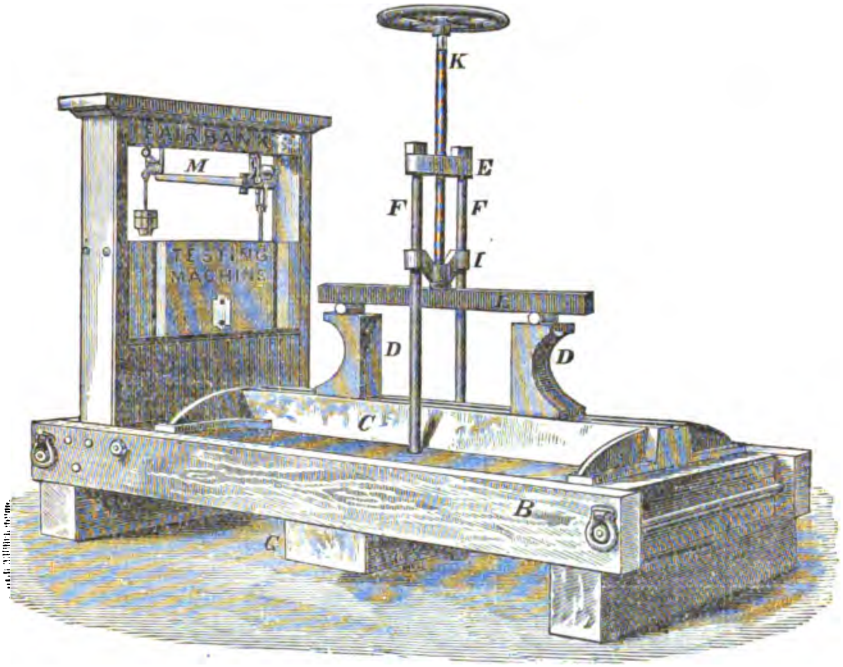

Fig. 12.—FAIRBANKS' TRANSVERSE TESTING-MACHINE.

In testing ductile metals with this machine, it will be noticed that results are obtained very different from those with dead loads when the bar is allowed to rest under stress for any length of time. In the test by dead loads, when a load is placed on a bar and the deflection is allowed to increase, the load continues to act as long as the test continues. In the test by the pressure-screw and scale-combination, the deflection is maintained constant by the screw, while the decrease of resistancing of the bar is shown by the dropping of the scale-beam, and its balancing by a smaller weight, moving the sliding poise to a lower figure on the beam.

To test a ductile metal by the pressure-screw exactly as with dead loads, it would be necessary to continue turning the hand-wheel just rapidly enough to keep the scale-beam constantly balanced, so that the pressure would remain constant and the deflection increase as in the test under dead loads. With very ductile metals, which show under some loads a decreasing, and under heavier loads a rapidly increasing, rate of increase of deflection, this would be impracticable. To observe the effect of time in tests of the ductile metals, therefore, the deflection was measured when the scale-beam balanced at a certain figure, and then, as the beam dropped, showing a decrease of resistance of the bar to stress, the poise was pushed back until the beam balanced again, and the figure on the beam recorded and the time noted. As the beam dropped again it was again balanced, and so on as long as it was desired to continue the test.

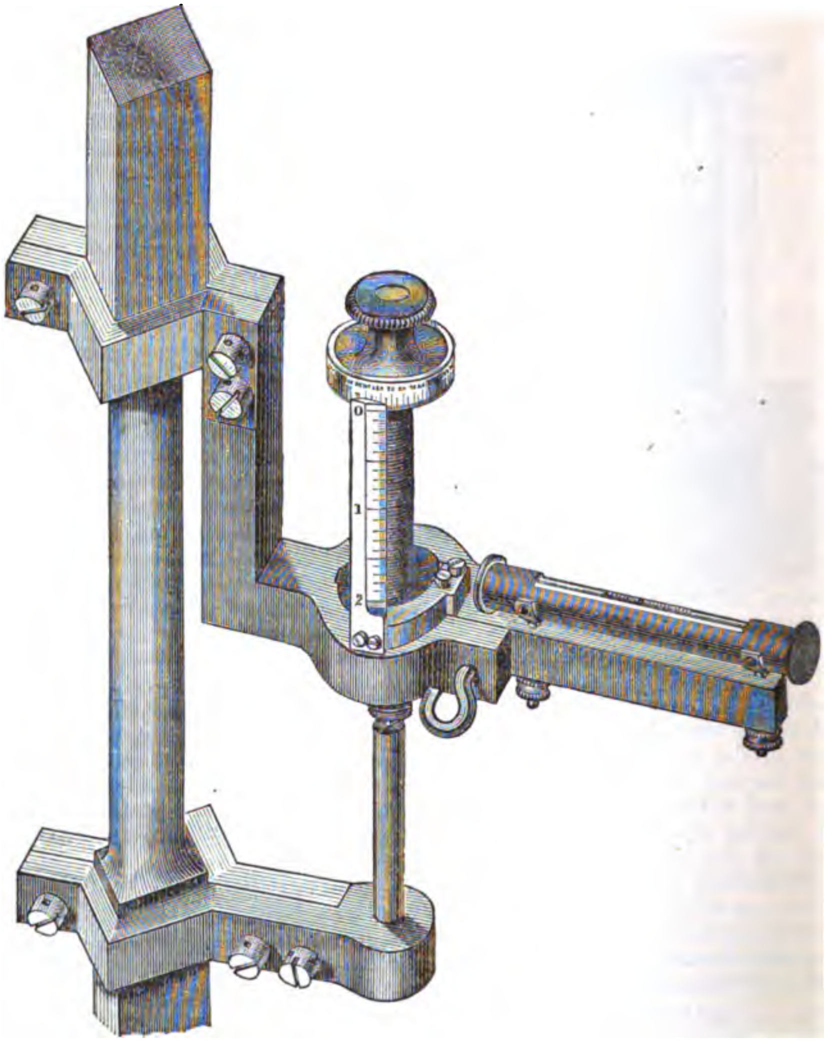

FIG. 13.

In the appended tables of the tests of the second series, therefore, it will be observed that when "time tests" are made, instead of noting the increase of deflection with various times of leaving under stress, as in the first series, the decrease of resistance is noted, as measured on the scale-beam. The decrease of resistance to stress is also frequently noted in these tables by the words "beam sinks," when the beam was observed to drop while taking the reading of the deflection, but when the test was at once continued without stopping for "time tests."[*] The deflections of the bars tested in this apparatus were measured by an instrument (Fig. 13) designed for the purpose, which consists of a micrometer screw and contact level, similar to the instrument used by the United States Coast Survey for comparing standard measures of length.

The screw has 40 threads to the inch, and the head is divided into 250 parts, so that a turn of the screw through a distance indicated by one division on the scale corresponds to an advance of the screw through its nut of $\frac{1}{10000}$th of an inch. The screw and the nut in which it works are carried by a bronze piece supported by two pivot screws. This piece also carries a very delicate astronomical level. The readings of the head of the screw are taken when the bubble of the level is exactly in the center of its glass, and, when care is taken, the readings are given with accuracy to the $\frac{1}{10000}$th of an inch. The instrument was tested carefully in the Physical Laboratory of the Stevens Institute of Technology, and the pitch of the screw was found to be uniform within the limits of error of the reading, and the level to have the required delicacy of action.

The pitch of the screw, however, has an error which is proportional to its length, amounting to 0.000741 inch in each inch of its length, the inch indicated by the instrument being, accurately, 0.99925 inch.

In using this instrument to measure deflections, in tests by transverse stress, it is mounted on an iron standard which is bolted firmly to the middle of the heavy base-plate of the machine, and placed in such a position that the end of the micrometer screw rests on a flat surface on the upper side of the piece which acts on the middle of the bar to be tested, and through which the pressure is applied. This piece is guided by the rods which sustain the nut in which the large pressure-screw rotates, in such a manner that it can only move in a vertical direction.

A special test was made of the accuracy of the method of measuring deflections, and a slight error was found to arise from the deflection of the bed-plate of the testing-machine. This error was found to amount to 0.0050 inch when the machine was strained to its working limit, viz, 4,000 pounds, and it was also found to be proportional to the stress, or 0.00000125 inch for each pound of stress, which error, if absolute accuracy is desired, should be added to the observed deflections.

In testing the softer metals an error is introduced by the compression of the bar at the point which is touched by the pressure-block and the points which rest on the rollers. The effect of this compression can, in some cases, be seen on the bars after they have been tested. This error seemed to be nearly constant after the application of about a hundred pounds, the pressure-block and rollers appearing to form permanent beds for themselves. It may partially account for the apparently greater increase of deflections for equal increments of load near the beginning of the test than elsewhere near the elastic limit, and therefore for the apparent irregularity in the moduli of elasticity.

Tables are appended giving the records of the test of each bar, and the following table presents a condensed summary of all results:

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[*] See paper by the writer "On the Rate of Set," &c., Appendix.

TABLE VIII.—SECOND SERIES—ALLOYS OF COPPER AND TIN.

Tests by Transverse Stress.

No.	Mean composition by analysis.		Length between supports.	Breadth.	Depth.	Breaking load.	Modulus of rupture.	Total deflection.	Limit of elasticity.		First set of 0.01 inch.		Modulus of elasticity. $E=\frac{Pl^3}{4\Delta bd^3}$			Remarks.
	Copper.	Tin.	l	b	d	P	$R=\frac{3Pl}{2bd^2}$	Δ	Load. P_1	Corresponding value of. $R_1=\frac{3lP_1}{2bd^2}$	Load. P_2	Corresponding value of. $R_2=\frac{3lP_1}{2bd^2}$	P	Δ	E	
			Inches.	*Inches.*	*Inches.*	*Pounds.*		*Inches.*	*Lbs.*		*Lbs.*					
31	99.09	0.87	22	0.956	0.977	360	13,014	0.1568	200	7,230	200	7,230	200	0.0674	8,860,059	Bar defective.
32	94.11	5.43	22	0.956	0.982	1,080	38,659	8.+	400	14,317	400	14,317	400—200	0.0433	13,581,817	Bent.
33	88.41	11.59	22	0.973	0.977	1,700	60,403	4.+	600	21,319	600	21,319	600—120	0.1129	12,472,655	
34	82.70	17.34	22	0.950	0.970	1,840	67,930	0.6125	1,040	38,395	1,040	38,395	840	0.1702	15,152,664	
35	77.56	22.25	22	0.965	0.968	820	29,926	0.1606	820	29,926	820	29,926	800	0.1606	15,149,535	
36	72.89	26.85	22	0.998	1.004	290	9,512	0.0475	290	9,512	290	9,512	240	0.0386	16,387,041	
37	67.87	32.10	22	0.964	0.987	270	9,477	0.0520	270	9,477	270	9,477	270	0.0520	14,896,691	
38	62.42	37.48	9	0.985	0.995	210	2,907	0.0185	210	2,907	210	2,907	200— 80	0.006	3,156,575	Modulus of elasticity doubtful.
39	57.88	42.05	17	1.000	0.985	142	8,732	0.0210	142	8,732	142	8,732	102	0.0150	8,739,548	Do.
40	53.46	46.55	9	1.015	1.000	150	1,995	0.0080	150	1,995	150	1,995	141— 81	0,0025	4,306,523	Do.
41	47.27	52.72	15	0.962	0.980	230	5,601	0.0186	230	5,601	230	5,601	220	0.0186	11,022,250	
42	43.99	55.91	18	0.995	0.995	222	6,084	0.0357	222	6,084	222	6,084	142	0.0215	9,824,600	
43	37.10	62.90	22	0.970	0.990	200	6,942	0.0799	100	3,971	......	....	40	0.0106	10,672,961	
44	30.76	69.19	22	0.985	0.990	210	7,178	0.1122	100	3,418	......	....	80	0.0319	6,984,987	
45	26.63	73.17	22	0.978	0.985	320	11,128	0.2204	140	4,868	160	5,564	40	0.0146	7,803,107	
46	22.10	77.58	22	0.980	0.992	400	13,687	0.4051	120	4,106	......	....	60	0.0197	8,474,849	
47	16.70	83.23	22	0.996	0.983	300	10,288	0.5332	80	2,744	100	3,429	40	0.0153	7,356,258	
48	11.69	88.27	22	0.985	0.990	300	10,254	1.0760	60	2,051	100	3,418	40	0.0141	7,901,458	
49	6.05	93.77	22	0.990	0.995	290	9,764	3.67+	60	2,020	100	3,367	40	0.0137	7,969,719	Bent.
50	2.11	97.68	22	0.991	0.997	250	8,375	3.93+	60	2,010	......	....	....	....	6,692,585	Do.

NOTES ON THE TESTS BY TRANSVERSE STRESS.

Comparing the results given in the above table with those of the transverse tests of the first series, given in Table II, page 278, it will be seen that there is a very close resemblance, indicating that there is a definite law connecting the strength with the composition of the copper and tin alloys, and that a regular curve can be laid down expressing this law.

It will be seen that in the second series the maximum strength was shown by No. 34 (82.72 copper, 17.33 tin), while in the first series it was exhibited by No. 7 (80.95 copper, 18.84 tin), which differed but little from it in composition. In both series there is a regular but rapid decrease of strength to alloys No. 13 (56.70 copper, 43.17 tin) of the first series, and No. 40 (53.46 copper, 46.54 tin) of the second series. From these compositions to the end of each series all of the bars possess but little strength, but there is a slow and somewhat irregular increase of strength from No. 13 and No. 40 to No. 21 (23.35 copper, 76.29 tin) in the first series, and No. 46 (21.60 copper, 77.58 tin) in the second series, which bars give what has been called the "second maximum" points in the curves of each series. Their resistances then gradually decrease to the end of each series, the bars at the end giving the "second minimum" points in each curve. The irregularity in strength in the latter part of the first series does not occur in the second series, since the latter was tested with more uniformity as to time than the former.

The results of these tests do not seem to corroborate the theory given by some writers, that peculiar properties are possessed by the alloys which are compounded of simple multiples of their atomic weights or chemical equivalents, and that these properties are lost as the compositions vary more or less from this definite constitution. It does appear that a certain percentage composition gives a maximum strength and another certain percentage a minimum, but neither of these compositions is represented by simple multiples of the atomic weights.

Besides, there appears to be a perfectly regular law of decrease from the maximum to minimum strength which does not seem to have any relation to the atomic proportions, but only to the percentage composition.

Referring to the appended tables, giving the record of the test of each bar, and the plate of plotted curves which accompanies them, the following observations may be made concerning these tests:

Bar No. 31 (99.09 copper, 0.87 tin).—This bar proved upon test to be a bad casting, and apparently had a crack in the middle which was not discovered till after 360 pounds pressure had been placed on it. The limit of elasticity appeared to be reached at about 200 pounds, and a set of 0.01 inch was observed at the same point, both of which indicated the deflective strength before rupture. The modulus of elasticity also was much less than those of other bars of nearly the same composition. After breaking, the fracture showed the metal to be full of blow-holes and it had a partially oxidized appearance. As bar No. 2 (97.89 copper, 1.90 tin) of the first series was also defective, it is indicated that faulty castings are very likely to occur with alloys containing less than 3 per cent. of tin. It is possible, however, that sound bars may be made if the metal is poured at the proper heat and cooled at the proper rate. As this bar was defective, it is omitted from the plotted curves (Plate I).

Bar No. 32 (94.10 copper, 5.43 tin).—This proved to be a good bar, and bent without breaking at a load of 1,080 pounds. From the plotted curves of stresses and deflections (Plate XVII) it appears that the limit of elasticity was reached at about 600 pounds.

A set of 0.0145 inch took place at 400 pounds. At 440 pounds the scale-beam was observed to drop while taking the deflection, immediately after it had been balanced, showing a decrease of resistance to constant deflection, which has been commented upon in describing the action of the machine (page 325). This also occurred at every load beyond 440 pounds, although it is not noted in the table. It is to be understood that in all tests in which a decrease of resistance to stress is noted, that decrease also took place at every load succeeding that at which it is first observed to the end of the test.

A "time test" was made at 600 pounds, showing a decrease of resistance in 2 minutes to 586 pounds, and in 1 hour 48 minutes to 562 pounds.

Bar No. 33 (88.40 copper, 11.59 tin).—This bar proved much stronger than No. 32, breaking at a load of 1,700 pounds, after a deflection of about 4 inches. A set of 0.0112 inch was observed at 600 pounds, and the limit of elasticity is taken at this point. At 720 pounds the bar showed a decrease of resistance, the scale-beam slowly sinking below its middle position. This bar differed but little in composition from No. 6 (87.15 copper, 12.73 tin) of the first series, which was found to be defective by reason of liquation, and it confirms the indication mentioned under the transverse test of No. 6, that the liquation was not caused by the particular mixture or composition, but by some peculiarity in casting or cooling. The fracture of this bar was in color a light grayish-yellow, slightly darker in the center, and of an earthy appearance, entirely devoid of luster; a few very small blow-holes were seen around the edges of the fracture. It resembled somewhat the more homogeneous fractures of bar No. 5 (90.27 copper, 9.58 tin). Its shape was trapezoidal, a characteristic of all fractures by transverse stress of metals possessing considerable ductility. The measurement of this fracture showed the breadth at the top to be 1.003 inches and at the bottom 0.937 inch. The depth was 0.972 inch. The original section of the bar was rectangular, breadth 0.973 inch, and depth 0.977 inch.

Bar No. 34 (82.72 copper, 17.23 tin).—This bar was the strongest of the series, and also stronger than any bar in the first series. It broke at 1,840 pounds, after a deflection of 0.6125 inch. A set of 0.0098 inch was observed at 1,000 pounds, and the limit of elasticity was reached at 1,040 pounds.

In breaking, the bar gave out a ringing sound, and the two halves flew out from under the pressure-screw, and were found on the platform about four feet apart. The fracture was of a pinkish-gray color, very fine, granular, and homogeneous, except a spot in the center, which appeared to be a mottled mixture of the pinkish-gray with a dull, earthy, yellowish-gray. There were no signs of a decrease of resistance throughout the test during the times necessary to take readings of deflections (from 30 seconds to 1 minute each). The fracture took place just as the last reading of deflection was taken, and about 30 seconds after the beam was balanced at 1,840 pounds, the beam remaining balanced until the instant of rupture. The appearance of the fracture and the behavior under stress were very similar to those of bar No. 7 (80.95 copper, 18.84 tin), which broke at 1,750 pounds, and was the strongest bar of the first series. It appears that the maximum strength is associated with a peculiar color, a reddish or pinkish gray, which marks the change from the ductile alloys to the brittle ones, and occurs between the percentages of tin which give a silver-white alloy in which no trace of copper could be detected by the eye, and the reddish-yellow to yellowish-gray alloys like No. 6 (lower end of bar) and No. 33.

The tests of No. 7 and No. 34 are not sufficient of themselves to determine with accuracy the composition which gives the maximum strength of all the alloys of copper and tin; but from the plotted curves of the tests of both series it appears evident that it lies between 82.5 and 85 per cent. copper.

Bar No. 35 (77.56 copper, 22.25 tin).—This bar had less than half the strength of No. 34, breaking at 840 pounds after a deflection of 0.1606 inch, thus again exhibiting the result shown in the test of the first series, the very rapid decrease of strength between 80 and 75 per cent. of copper. In all its qualities it closely resembles No. 8 (76.63 copper, 23.24 tin) of the first series. The color of the fracture was the same, a very slight pinkish-gray, with a very fine granular structure, but showing slight radiated lines of cooling which were not present in the fractured surface of No. 8. No set amounting to 0.01 inch could be detected during the test, and the limit of elasticity was not reached before fracture; the bar, therefore, possessed all the qualities of the brittle alloys, combined with a considerable degree of strength.

Bar No. 36 (72.89 copper, 26.85 tin).—This bar also illustrates the sudden decrease of strength after passing the maximum, breaking at 290 pounds, after a deflection of 0.0475 inch. The limit of elasticity was not reached before fracture, and no set amounting to 0.01 inch was found. The fracture was of a brilliant silver-white color, with a very faint tinge of pink. It had a curved shape, like those of No. 9 (69.84 copper, 29.88 tin) and No. 10 (68.58 copper, 31.26 tin) in the first series, and, like them, showed a laminated or prismatic structure. In all respects the bar resembled No. 9 and No. 10, except in the pinkish shade of color, which was absent in both of the latter. It appears, therefore, that the change in color from light pinkish-gray to silver-white takes place between the compositions containing 76.63 and 72.89 per cent. of copper, and that the change is gradual between these limits.

Bar No. 37 (67.87 copper, 32.09 tin).—This bar was a little weaker than No. 35, breaking at 270 pounds, after a deflection of 0.0520 inch. Like all of the brittle bars, it had no elastic limit before fracture, and no set amounting to 0.01 inch. The fracture was precisely similar to that of No. 10 (68.58 copper, 31.26 tin) of the first series.

Bar No. 38 (62.42 copper, 37.48 tin).—The piece of this bar which was tested by transverse stress was only 9 inches in length between supports, the bar having broken in the emery-wheel planer, as already mentioned on page 324. This piece broke at 210 pounds, giving a modulus of rupture, $R = \frac{3\,Pl}{2\,bd^2}$, of 2907 pounds, or less than one-third that of No. 37. The deflection with 200 pounds stress was 0.0185 inch. This deflection appears to give a very low modulus of elasticity, only 2,000,000 pounds, or 3,000,000 if the modulus is taken between the loads of 80 and 200 pounds to eliminate the probably erroneous readings of deflection at the beginning of the test. The formula by means of which the modulus of elasticity is calculated, $E = \frac{Pl^3}{4\,\Delta\,bd^3}$, however, is not exact for short specimens, as it does not take into account the effect of shearing stress, as has been observed on page 281.

The figures of moduli of elasticity in all the bars of this series which have less than the standard length of 22 inches between supports are therefore probably much too small. Moreover, the effects of all the errors in the test, those of observation, those due to compression of the points of the bar touched by the supports and by the pressure-block, and those due to the unevenness of the bearing, will all be increased and will tend to increase the apparent deflection.

The fact that liquation occurred in this bar was noted on page 324. The fracture by transverse stress also exhibited liquation as it differed in appearance from both of the accidental fractures. It was of a dark gray color and stony structure, with no radiated lines of laminæ, and was not homogeneous, parts being brilliant and parts dull.

Bar No. 39 (57.87 copper, 42.05 tin).—The length of the bar when tested was 17 inches. It broke at 142 pounds after a deflection of 0.021 inch, giving a modulus of rupture somewhat higher than No. 38. The apparent modulus of elasticity is much higher than that of No. 38. The fracture was of a light-gray color and stony structure, showing some radiated lines.

Bar No. 40 (53.46 copper, 46.54 tin).—This bar was only 9 inches long between supports, and it proved to be the weakest of the series, breaking at 150 pounds with a deflection of only 0.008 inch, giving a modulus of rupture of 1,995 pounds. The apparent modulus of elasticity is very low, as in the cases of the other short bars. The color of the fracture was light gray, and it had a radiated lamellar structure. It was not distinguishable from the fracture of No. 39. It was also similar in appearance to No. 13 (56.70 copper, 43.17 tin), which was the weakest bar in the first series.

Bar No. 41 (47.27 copper, 52.72 tin).—The length of this bar was 15 inches between the supports. It was much stronger than No. 40, breaking at 230 pounds after a deflection of 0.0186 inch, giving a modulus of rupture of 5,601 pounds. From the position of this test in the curve strengths of the series it is seen that it also indicates a law of gradual increase of strength from the bar of minimum strength, No. 40, to the bar of "second maximum" strength, No. 46 (21.60 copper, 77.58 tin), which was also shown in the test of the first series. The fracture was very much like that of No. 40.

Bar No. 42 (43.99 copper, 55.91 tin).—This bar was 18 inches in length between the supports. It was a little stronger than No. 41, breaking at 222 pounds, giving a modulus of rupture of 6,084 pounds after a deflection of 0.0357 inch. The bar did not break in the middle, as is nearly always the case in transverse tests, but 4 inches from the middle, or 5 inches from the upper or A end of the bar. The longer piece (marked E–c) remaining after the test was then also tested, being 13 inches in length between the supports. It gave a result slightly higher than the original bar, breaking at 362 pounds, giving a modulus of rupture of 6,605 pounds after a deflection of 0.031 inch. The apparent modulus of elasticity given by this test is only about half of that given by the original bar, which only serves to confirm the statement already made as to the unreliability of the moduli of elasticity derived from tests of very short bars. The fractures were similar in color to those of No. 41, but showed a compact stony, instead of a radiated and laminated, appearance. The accidental fracture near the bottom of the original bar, however, did show the radiated structure, as did also bar No. 43.

The analyses of turnings from two different parts of this bar showed that a large amount of liquation had occurred, the turnings from the lower part of the bar containing more than 22 per cent. less copper than those from the upper. This is sufficient to account for the breaking in a section other than the middle, and for the difference in appearance of the fractures.

Bar No. 43 (37.10 copper, 62.90 tin).—This bar was of the standard length, 22 inches, and shows an increase of strength over No. 42, breaking at 200 pounds, or at a modulus of rupture of 6,942 pounds after a deflection of 0.0799 inch. A set of 0.0202 inch was observed just before rupture took place, thus showing more ductility than either of the five previous bars. From this point to the end of the series the ductility increases. It will be observed that in this, and in all of the more ductile bars containing large percentages of tin, the moduli of elasticity appear to decrease from the beginning of the test, while in the brittle bars they either remained nearly constant or showed a slight increase. In the latter the limits of elasticity, or points at which the ratio of distortion to stress increases are not reached before fracture occurs. In the former, they occur very near the beginning of the tests, but its exact place is difficult to determine. On the plate of curves of deflections this is plainly seen, as the curves of these ductile bars show a curvature concave to the axis of abscissas almost from the beginning of the test. The limit of elasticity is usually taken as the point at which the curve begins suddenly to become concave toward the axis, but in the ductile bars in which this point of change is not plainly marked, it is assumed to be that point at which the *greatest* change of curvature seems to take place, or a little before the curve assumes a nearly horizontal direction. By inspection of the curve of No. 43 its limit of elasticity is determined to be pounds. When 100 pounds had been placed on the bar, a decrease of resistance to stress was noted, the scale-beam dropping while the reading was being taken, as was observed in the cases of bars No. 31 to No. 34. This was also observed in all bars from No. 43 to the end of the series.

The fracture was of a light-gray color, and showed very large prismatic crystallization similar to that of No. 19 (34.22 copper, 65.80 tin) of the first series.*

Bar No. 44 (30.76 copper, 69.19 tin).—This bar also showed the increasing strength and increasing ductility of this part of the series as the percentage of tin increases. It broke at 210 pounds after a deflection of 0.1122 inch. A set of 0.0325 inch was observed at 200 pounds. From the curves of deflections (Plate XVII) the limit of elasticity appears to have been reached at 100 pounds, at which load the bar first exhibited a decrease of resistance to constant deflection. The appearance of the fracture was precisely like that of No. 43.

Bar No. 45 (26.62 copper, 73.18 tin).—This bar was considerably stronger and more ductile than No. 44, breaking at 320 pounds after a deflection of 0.2204 inch. A set of 0.0145 inch was observed at 160 pounds, and from the curve the limit of elasticity appears to have been reached at 160 pounds. The decrease of resistance under constant deflection was first found at 80 pounds, and a "time test" of this decrease was made at 160 pounds. As shown in the table, after the beam had been balanced for the second time at 160 pounds, the resistance decreased in 1 minute to 154 pounds, in 3 minutes to 150 pounds, in 44 hours to 104 pounds, and in 69 hours to 100 pounds, showing a gradually decreasing rate of the decrease. The fracture was similar in color to those of No. 43 and No. 44, but the crystals were much smaller, and had more of a granular appearance.

Bar No. 46 (22.10 copper, 77.58 tin).—This bar gave the "second maximum" point of strength in the curve of the series, breaking at 400 pounds after a deflection of 0.4051 inch. It closely resembled in all its qualities the bar which gave the "second maximum" in the first series, No. 21 (33.35 copper, 76.29 tin), but did not have a cavity throughout its length such as was seen in the latter. A set of 0.0047 inch was observed at 100 pounds, and one of 0.0357 inch at 200 pounds. The decrease of resistance with time was first observed at 100 pounds; from the curve of deflections the limit of elasticity is seen to be at pounds. The fracture was similar to that of No. 45.

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* See description of fracture of No. 19 by Professor Leeds, page 290.

Bar No. 47 (16.70 copper, 83.23 tin).—This bar proved to be a little weaker than No. 46, thus confirming the law of decrease of strength from the second maximum to the end of the series. It broke at 300 pounds after a deflection of 0.5332 inch. A set of 0.0092 inch was observed at 100 pounds, and from the curve of deflections the limit of elasticity was apparently reached at about 100 pounds. The fractured surface was similar to that of No. 46.

The phenomenon of *decrease of set with time* was observed for the first time with this bar; the table of the record of test giving the full record of all the observations made. On relieving the bar of all pressure except that due its own weight, and except a very slight pressure (a few ounces) to insure that the pressure-block actually touched the bar and was not raised from it, the scale-beam balanced at 5 pounds, and the reading of the set was made. While reading the set the scale-beam was observed to rise, indicating *increase* of resistance to deflection, as it had similarly been observed to drop when resistance to stress took place. A number of observations of this increase of resistance to the permanent deflection were made, and also of the decrease of set, as measured by running back the pressure-screw till the scale-beam again balanced at 5 pounds, and taking additional readings. The result of these observations, which are all given in the table, showed that in one observation of 39 minutes the resistance of the bar, as measured by the scale-beam, increased 18 pounds, and that in 2 hours 20 minutes the set decreased the amount of 0.0239 inch.

This fact of the decrease of set with time has since been confirmed by a large number of tests made on the same machine, and it has also been observed by other experimenters. It indicates that what has been hitherto called the "permanent set" of metals is in reality not entirely permanent, but is partially, at least, temporary.*

Bar No. 48 (11.68 copper, 88.25 tin).—The result of the test of this bar was almost precisely like that of No. 47, but it showed considerably greater ductility. It broke at 300 pounds, after a deflection of 1.0760 inches. A set of 0.0120 inch was observed at 100 pounds. The limit of elasticity is taken at 100 pounds. The decrease of resistance to stress was first noted at 80 pounds. The phenomenon of decrease of set with time was also observed with this bar, a test of 20 minutes' duration showing a decrease of set of 0.0234 inch. The fracture was of a light-gray color with a rough granular structure.

Bar No. 49 (6.05 copper, 93.77 tin).—This bar was weaker and much more ductile than No. 48, bending to a deflection of 3.67 inches without breaking at a load of 290 pounds. A set of 0.0128 inch was observed at 100 pounds, and the limit of elasticity seems to be reached at about this point. The decrease of resistance to stress was first observed at 80 pounds. No tests were made of the decrease of set with time.

Bar No. 50 (2.11 copper, 97.68 tin).—This bar was still weaker than No. 49, bending to a deflection of 3.93 inches, without breaking at a load of 250 pounds. A set of 0.0164 inch was observed at 100 pounds, and the limit of elasticity seems to be reached at about 60 pounds. The decrease of resistance with time was first noticed at 60 pounds. At 210 pounds the beam was caused to balance twice after it had dropped, the deflection at the same time being increased from 0.85 to 1.08 inches.

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* See paper by the writer, &c.

This indicated that a much less load than 250 pounds would have caused he final recorded deflection of 3.93 inches, if sufficient time had been given to it.

It will be observed, on comparing the results of the tests of No. 49 and No. 50 with those of bars of nearly similar composition in the first series, that the former gave much higher results than the latter. This is due entirely to the method of test, or rather to the time taken by the different methods. In the tests of the ductile bars of the first series, by dead loads, as already stated, the load acted constantly to produce an increased deflection while the reading was being taken, and thus a much less load was required to produce a certain deflection than would have been required if the test had been made more rapidly. In the tests of the second series all the conditions of a rapid test were fulfilled, since the deflection was not increased while the reading was being taken, and also since the actual time occupied by the test was very much less in consequence of the greater convenience of handling the apparatus.

TESTS BY TENSILE STRESS.

Second series. Alloys of Copper and Tin.

The bars of the second series, after having been tested by transverse stress, as above described, were shaped by being turned in a lathe into pieces for test by tensile stress of the same shape as those of the first series, with the cylindrical portion of the test-piece 5 inches in length and 0.798 inch in diameter, or ½ square inch sectional area. The bars, which were too brittle to be turned, were tested in their original rectangular section.

The tests were made on the testing-machine (Fig. 6, page 292), described under the tests of the first series.

The elongations were measured by means of the contact-level and micrometer-screw (Fig. 13, page 326), which was used in measuring the deflections in the transverse tests, and which has already been described. In adapting it to tensile tests, the bronze piece containing the two pivot-screws which support the piece carrying the level and nut was firmly clamped by a screw to the rectangular head of the test-specimen just above the cylindrical portion.

At the bottom of the specimen was clamped a similar bronze piece, which carried a small steel cylinder, with a flat upper surface, which the end of the micrometer-screw was brought to touch, and upon which it rested, being free to move about the pivot-screws during the test When the test-piece, with the measuring-apparatus clamped to it, was placed in the grips of the testing-machine it was brought into a vertical position, and the micrometer-screw was turned in its nut until the bubble of the level was in its middle position. As the test proceeded and the piece elongated, the distance between the two pieces of the measuring-apparatus increased exactly to the extent of the elongation, and the level shifted, requiring the micrometer-screw to be advanced an amount equal to that of the elongation to bring the bubble again to its original position.

The apparatus was found to give good results, except at the beginning of the test, when the piece appeared to take a very slight curvature, the effect of which was at times to cause the apparent elongation to be greater or less than the true elongation.

The curvature or bending of the test-specimen may be produced by either of several causes, or by a combination of them all. These are chiefly the existence of a blow-hole, or any want of homogeneity in one side of the test-specimen, the fact of the heads of the test-specimen not being accurately symmetrical with the cylindrical portion, or the side strain brought by the testing-machine by reason of the line of stress not being accurately in line with the axis of the test-specimen.

These errors appear to exist only in that part of the test which is below the elastic limit of the specimen, as after that point the stress pulls the piece into the line, which it retains till the end of the test. The bending is so slight usually that it has not been detected, so far as the writer is aware, by any other means of measurement than the one herein described, which magnifies the extensions considerably.

Because of these errors, the figures given in the tables for elongations near the beginning of the test before they amount to 0.01 inch are in many cases not reliable. Where the elongations are greater than this amount, the figures are considered very accurate, with perhaps a slight error, which is constant throughout the test. For the same reason, the recorded figures of elongations cannot be relied upon to give correct moduli of elasticity by tensile stress, which might have been done if the error due to the bending of the specimen had been entirely eliminated. With the exception of these errors, the measurements are believed to be much more nearly correct than those of the first series, which were made simply by means of a pair of finely-pointed dividers and readings on a scale to $\frac{1}{100}$th of an inch.

The results of the tests by tensile stress of the second series have been entirely confirmatory of those of the first series and of the tests by transverse stress of both series.

The appended tables contain the complete records of the tests of each bar. The following table presents a condensed summary of results:

TABLE IX.—SECOND SERIES—ALLOYS OF COPPER AND TIN.

Tests by Tensile Stress.

Number.	Composition by analysis.		Diameter of—		Total elongation—parts of original length.	Tenacity per square inch of—		Elastic limit—pounds per square inch.	Remarks.
	Copper.	Tin.	Original section.	Fractured section.		Original section.	Fractured section.		
			Inches.	*Inches.*		*Pounds.*	*Pounds.*		
31 A	99.40	0.52	0.798	0.770	0.0170	13,000	13,958	7,000	Defective bar.
31 B	98.79	1.22	0.798	0.770	0.0155	15,250	16,374	6,000	Do.
Mean ..	99.09	0.87	....	0.770	0.0163	14,125	15,166	6,500	
32 A	93.98	5.47	0.798	0.690+	0.0779	28,500	35,922	14,000	
32 B	94.23	5.39	0.798	0.720+	0.0706	27,300	32,844	14,000	
Mean ..	94.11	5.43	....	0.705	0.0743	27,900	34,383	14,000	
33 A	88.35	11.61	0.798	0.776	0.0226	29,000	30,658	20,000	
33 B	88.46	11.57	0.798	0.770	0.0485	33,200	35,648	22,000	
Mean ..	88.41	11.59	....	0.773	0.0356	31,100	33,153	21,000	
34 A	82.72	17.33	0.798	0.795	0.0071	40,200	40,492	....	
34 B	82.69	17.34	0.798	0.798	0.0071	32,200	32,200	....	
Mean ..	82.70	17.34	....	0.797	0.0071	36,200	36,346	....	
35 A	77.41	22.27	0.798	0.798	0.0042	23,600	23,600	....	
35 B	77.71	22.23	0.798	0.798	0.0066	25,700	25,700	....	
Mean ..	77.56	22.25	....	....	0.0054	24,650	24,650	....	
36 A	72.85	26.80	....	....	....	6,500	6,500	....	Rectangular section, 0.998″×1.002″,
36 B . .	72.94	26.90	....	....	....	6,485	6,485	....	Do ...1.010″×1.000″.
Mean ..	72.89	26.85	....	....	....	6,493	6,493	....	

TABLE IX.—SECOND SERIES—ALLOYS OF COPPER AND TIN.

Tests by Tensile Stress—Continued.

Number.	Composition by analysis.		Diameter of—		Total elongation—parts of original length.	Tenacity per square inch of—		Elastic limit—pounds per square inch.	Remarks.
	Copper.	Tin.	Original section.	Fractured section.		Original section.	Fractured section.		
			Inches.	*Inches.*		*Pounds.*	*Pounds.*		
37 A	67.66	32.22	....	....	....	1,644	1,644	....	Rectangular section, 0.975″×0.990″.
37 B	68.08	31.98	....	....	....	3,408	3,408	....	Do ...0.982″×0.985″.
Mean ..	67.87	32.10	....	....	....	2,536	2,536	....	
38 A	67.59	32.32	....	....	....	2,335	2,335	....	Do ...0.980″×0.992″.
38 C	53.69	36.27	....	....	....	....	....	....	
38 B	55.99	43.85	....	....	....	787	787	....	Do ...0.983″×0.990″.
Mean ..	62.42	37.48	....	....	....	1,561	1,561	....	
39 A	64.21	35.56	....	....	....	1,200	1,200	....	Do ...0.982″×0.990″.
39 B	51.54	48.54	....	....	....	1,553	1,553	....	Do ...0.988″×0.997″.
Mean ..	57.88	42.05	....	....	....	1,377	1,377	....	
41 A	47.10	52.86	....	....	....	1,919	1,919	....	Do ...0.968″×0.985″.
41 B ...	47.43	52.59	....	....	....	2,894	2,894	....	Do ...0.960″×0.990″.
Mean ..	47.27	52.72	....	....	....	2,407	2,407	....	
42 A	55.21	44.80	....	....	....	2,273	2,273	....	Do ...0.992″×1.004″.
42 B	32.77	67.02	....	....	....	1,924	1,924	....	Do ...0.995″×0.987″.
Mean ..	43.99	55.91	....	....	....	2,098	2,098	....	
43 A	37.62	62.36	0.798	0.798	....	2,800	2,800	....	
43 B	36.58	63.44	0.798	0.798	....	2,000	2,000	....	
Mean ..	37.10	62.90	....	....	....	2,400	2,400	....	
44 A	33.86	66.01	0.798	0.798	....	1,592	1,592	....	
44 B	27.66	72.37	0,798	0.798	....	3,052	3,052	....	
Mean ..	30.76	69.19	....	....	....	2,322	2,322	....	
45 A	26.64	73.15	0.798	0.798	....	3,360	3,360	....	
45 B	26.61	73.20	0.798	0.798	....	5,400	5,400	....	
Mean ..	26.63	73.17	....	....	....	4,380	4,380	....	
46 A	22.09	77.62	0.798	....	....	4,200	4,200	....	
46 B	22.11	77.54	0.798	0.796	0.0043	5,800	5,827	....	
Mean ..	22.10	77.58	....	....	0.6022	5,000	5,014	....	
47 A	16.74	83.11	....	....	....	....	....	....	
47 B	16.66	83.36	0.798	0.797	....	2,816	2,822	....	
Mean ..	16.70	83.23	....	....	....	....	....	....	
48 A	11.67	88.25	0.798	0.795	....	3,416	3,440	....	
48 B	11.70	88.24	0.798	0.795	0.0110	4,180	4,210	2,000	
Mean ..	11.69	88.24	....	0.795	0.0055	3,798	3,825	....	
49 A	6.07	93.75	0.798	0.710	0.1742	6,192	7,981	3,200	Tenacity per square inch fractured section doubtful.
49 B	6.03	93.79	0.798	0.680	0.2302	6,000	8,260	2,000	Do.
Mean ..	6.05	93.77	....	0.695	0.2022	6,096	8,121	2,600	
50 A	2.18	97.60	0.798	0.545	0.4100	5,600	12,002	1,200	Do.
50 B	2.03	97.77	0.798	0.530	0.3900	5,600	12,691	1,200	Do.
Mean ..	2.11	97.68	....	0.538	0.4000	5,600	12,397	1,200	

NOTES ON THE TESTS BY TENSILE STRESS.

No. 31.—As was shown by the transverse test of this bar, it was a defective casting. The tensile tests also gave very low results, and they are rejected from the tables and from the curves of average results of the series (Plates II, VII, VIII). The turned surfaces of the test-pieces from this bar revealed a liquation or separation of the metals into two alloys, or possibly a heterogeneous mixture of unalloyed copper, with an alloy containing a considerable amount of tin. The turned surface was in general of a copper-red color, not at all distinguishable from the appearance of pure copper; but there were small yellow spots irregularly distributed over the whole surface. The fractures showed a similar appearance, the larger portion being of a copper color, and the remainder consisting of a few yellowish-gray spots. The turned surfaces and the fractured surfaces also contained several small blow-holes.

No. 32 (94.40 copper, 5.43 tin).—The two pieces from this bar gave very similar results, which show a fair degree of strength for metal of its composition cast in the ordinary manner. The fractures were of a yellowish-red color, and earthy structure, and contained several very small blow-holes.

No. 33 (88.40 copper, 11.59 tin).—The two test-pieces showed a somewhat greater strength than those of No. 32. The fractured surfaces were of a reddish-yellow color, and earthy structure, and contained several very small blow-holes. These were more numerous in No. 32 A than in No. 32 B, which may account for the greater strength of the latter.

No. 34 (82.72 copper, 17.33 tin).—The average of the two tests of this bar showed considerably greater strength than No. 33, but the piece from the bottom of the bar was much weaker than that from the top, and slightly weaker than the bottom piece of No. 32. This does not appear to have been due to liquation, as the analyses of the turnings from the two tension-pieces give almost precisely similar results, which differ but little from the original mixture. It may possibly have been due to a more imperfect mixture of the metals in one portion of the bar than in another, causing a want of homogeneity, which is partly indicated by the appearance of the fractured surfaces. The fracture of No. 34 A was chiefly of a pinkish-gray color, similar to those of No. 7 and No. 8 of the first series. The structure was very finely granular, with an indistinct appearance of radiated lines of cooling. In the center was a spot about ¼ inch in diameter, which had a mottled mixture of the pinkish-gray and a yellowish-gray color. The fracture of No. 34 B was similar to that of No. 34 A, the larger part of the surface being of a pinkish-gray color and fine granular structure, but without any radiated lines of cooling. It also contained a spot in the center, which in this case was not mottled, but was of one color, a reddish or brownish gray.

The average tensile strength of the two pieces from this bar is higher than that given by any other bar in this series, and is also higher than that of any bar in the first series, agreeing in this respect with the results of the transverse tests.

No. 35 (77.56 copper, 22.25 tin).—The strength of this bar, as shown by the tensile tests, was much less than that of No. 34. The fractures have the same pinkish-gray color that was seen in No. 34, but a shade lighter. The structure shows an appearance of radiated laminæ, very close and compact. It is very similar to that of No. 9 (69.84 copper, 29.89 tin) of the first series, but the color is entirely different, the latter being nearly a silver-white. The fractures of both pieces of No. 35 were precisely alike, and a very small blow-hole was found in the center of each.

No. 36 (72.89 copper, 26.85 tin).—The tensile tests of this bar gave results agreeing precisely with those of the transverse test, showing great brittleness and lack of strength. The fractures were similar to that obtained by transverse test, being nearly silver-white in color, with a faint pinkish tinge, and a smooth radiated structure.

Bars No. 36 to No. 42 (43.99 copper, 55.91 tin), inclusive, were all tested with their original rectangular section unaltered, as they were too brittle to be turned in the lathe without danger of breaking. All of these bars gave much trouble in setting in the tensile-machine, their brittleness and hardness being so great that the grips of the machine would not firmly hold them. Most of them broke in the grips, and the figures representing their strengths are therefore in many cases perhaps too low. Several tests were generally made of each of the brittle pieces, and the maximum result is considered to be the one most nearly correct.

No. 37 (67.87 copper, 32.09 tin).—Both tension pieces were much weaker than those of No. 36. The fractures were similar, but the color was silver-white, entirely free from any pinkish shade.

No. 38 (62.42 copper, 37.48 tin).—The two test-pieces from this bar showed considerable difference in structure, due to liquation, which has already been noticed on page 346. The fracture of No. 38 A was exactly like those of the two pieces of No. 37, but that of No. 39 was of a dark-gray color and stoney structure, similar to that of No. 12 (62.31 copper, 37.35 tin) of the first series, which, as before observed, had the greatest density of the series.

No. 39 (57.87 copper, 42.05 tin).—The average results given by the two test-pieces from this bar show it to be the weakest of the series, and agree in this respect with the result of the test by transverse stress. The fracture of No. 39 A had a stony structure, and the color was a mottled mixture of dark gray and light gray, showing a separation into two alloys. That of No. 39 B was light gray throughout and contained radiated laminæ.

No. 40 (53.46 copper, 46.54 tin).—The pieces remaining from the test by transverse stress were too short to be tested by tension.

No. 41 (47.27 copper, 52.72 tin).—Three pieces were tested, giving various results, but all showing great weakness and brittleness. The fractures of all the pieces were alike in appearance, being light gray in color and of stony structure, with indistinctly defined radiated lamination.

No. 42 (43.99 copper, 55.91 tin).—The results of the two tests were similar to those given by No. 41. The fractures were light gray in color, with radiated crystalline structure. The analyses of chips from the two tension pieces of this bar showed a very large amount of liquation to have taken place in the casting. This would scarcely have been suspected from the appearance of the fractures.

No. 43 (37.10 copper, 62.90 tin).—This bar was much softer than the bars from No. 36 to No. 42, and the tension-pieces were turned in the lathe without difficulty. The average of the results shows a very little greater strength than that of No. 42. The fractures were of a light gray, with large radiated prismatic crystals.

No. 44 (30.76 copper, 69.19 tin).—The two tests gave results which differed considerably, but the average is about the same as those of the two tests of No. 43. The fractured surfaces also showed the same color and structure.

No. 45 (26.62 copper, 73.18 tin).—The results of the two tests differed similarly as those of No. 44, but both tests gave much higher results than the average of the latter, indicating an approach to the point of "second maximum" strength of the series. This was also shown in the tests of this bar by transverse stress. The fractures were of a light-gray color, similar to those of Nos. 42 to 44, but were not entirely homogeneous in structure, being coarse granular at the exterior portions of the surface and laminated in the center.

The analyses do not show any difference in composition in the two ends of the bar sufficient to account for any difference in strength or in appearance of the fractures.

No. 46 (22.10 copper, 77.58 tin).—The average of the two tests shows still greater strength than No. 45, but it is not high enough to confirm the point of second maximum strength which was shown by the transverse tests, as it is surpassed by No. 49 and No. 50. The second maximum of both transverse and torsional tests is given by this bar, and bar No. 21 (23.35 copper, 76.29 tin) gave the second maximum in the first series by all three methods of test. The results of the test of No. 46 by tensile stress must therefore be regarded as exceptional, in so far as they give less strengths than No. 49 and No. 50. The curves of the strengths of the series by the different methods of test, moreover, show the tensile test of No. 49 and No. 50 to give higher results than the other methods of test of the same bar. This may probably be accounted for by the greater rapidity of the tests of No. 49 and No. 50, which was purposely made in order to eliminate the effect of flow of the metal with time. The pieces of No. 46 being of small ductility, the effect of time was not so perceptible.

The fractures of No. 46 were very similar to those of No. 45, showing want of homogeneity of structure, part being granular and part laminated. This may account for the weakness and irregularity of strength, as in the first series the second maximum strength was associated with a homogeneous granular structure.

No. 47 (16.70 copper, 83.23 tin).—Only one piece was tested from this bar, No. 47 B, the other having been broken in handling before being tested. It had a less strength than either of the pieces of No. 46, and had a somewhat similar structure, being irregularly lamellar and crystalline.

No. 48 (11.68 copper, 88.25 tin).—The two pieces showed very little greater strength than No. 47 B. The fractures show the change in structure seen in those of the first series just before the metals begin to exhibit great ductility, being fine granular, with small brilliant points scattered over the surface.

No. 49 (6.05 copper, 93.77 tin).—Both test-pieces gave very similar results and higher than the average of No. 46, thus apparently making No. 49 the bar of second maximum strength of the series, as stated in remarks on the test of No. 46. These pieces showed great ductility, the elongations being 17 and 23 per cent. of the original length. The section was also greatly reduced, and the resistance to stress decreased before rupture, making the actual tenacity per square inch of the fractured section uncertain. The same fact has been commented upon when describing tests by tensile stress of the first series.

No. 50 (2.11 copper, 97.68 tin).—The results of the two tests of this bar were similar to those of No. 49, but they showed a somewhat less strength, with a much greater ductility, the elongations amounting to 39 and 41 per cent. The pieces were greatly reduced in diameter throughout their whole lengths, and their surfaces were much distorted and wrinkled. The strength of the bar as indicated by the tensile tests is much greater than that shown by the transverse and torsional tests, probably on account of the shorter length of time occupied by the former method of test.

TESTS BY TORSIONAL STRESS.

The tests by torsional stress of the second series of copper and tin alloys were made upon the Autographic Recording Torsion Machine described under the tests of first series. (Fig. 8, page 302.)

In making tests of ductile metals, the rate of motion given to the handle of the worm, except when a slow or a rapid motion was purposely given to determine its effect, was as uniformly as possible, one revolution in 10 seconds. As the worm-wheel contained 80 teeth, this caused a rate of motion of the axle of the worm-wheel, and of the wrench at one end of the test specimen, of one revolution in about 13 minutes. In testing the brittle metals and the ductile metals within the elastic limit the rate of motion was always much slower.

The autographic strain diagrams obtained, one for each test, accompany this report, and tables giving the strength, ductility, and resilience of each specimen as calculated from the diagrams are appended.

The average results of all the test specimens obtained from each bar are given in the following table:

TABLE X.—SECOND SERIES—ALLOYS OF COPPER AND TIN.

Tests by Torsional Stress—Averages of Results calculated from the Autographic Strain Diagrams.

Number.	Mean composition by analysis.		Area of diagram.	Angle of torsion.	Ordinate.		Torsional moment.		Ductility, extension of exterior fiber.	Resilience.	Number of pieces tested.	Remarks.
	Copper.	Tin.			Maximum.	At elastic limit.	Maximum.	At elastic limit.				
			Square inches.	*Degrees*	*Inch.*	*Inch.*	*Foot-pounds.*	*Foot-pounds.*		*Foot-pounds.*		
31	99.09	0.87	1.95	37.75	0.62	0.28	66.50	31.75	0.0224	36.87	4	All pieces defective.
32	94.11	5.43	20.18	187.25	1.51	0.48	156.63	52.10	0.4318	368.33	4	
33	88.41	11.59	9.68	70.75	1.73	0.64	178.05	68.48	0.0730	175.23	4	
34	82.70	17.34	1.98	14.00	1.93	1.00	108.06	102.29	0.0032	35.85	4	
35	77.56	22.25	0.35	4.38	1.49	1.05	153.96	109.85	0.0003	6.46	4	
36	72.89	26.85	0.08	1.00	2.27	2.27	35.54	35.54	0.00003	0.89	2	
37	67.87	32.10	0.14	1.65	2.50	2.50	26.13	26.13	0.00009	1.08	2	
38	62.42	37.48	0.02	0.50	1.68	1.68	19.20	19.20	0.00001	0.15	2	
39	57.88	42.05	0.02	0.50	0.63	0.63	8.60	8.60	0.00001	0.16	1	
40	53.46	46.55	0.01	0.40	0.58	0.58	7.77	7.77	0.00001	0.08	2	
41	47.27	52.72	0.04	1.00	1.35	1.35	17.96	17.96	0.00003	0.34	2	
42	43.99	55.91	0.08	1.33	1.35	1.35	16.23	16.23	0.00006	0.60	3	
43	37.10	62.90	0.06	1.50	0.66	0.65	12.70	12.70	0.00004	0.20	4	
44	30.76	69.19	0.23	2.63	0.98	0.96	17.32	17.14	0.00014	0.73	4	
45	26.63	73.17	0.33	3.17	1.45	1.42	25.50	25.12	0.00018	1.06	8	
46	22.10	77.58	1.06	7.38	1.56	1.50	27.80	26.45	0.0012	3.31	4	
47	16.70	83.23	1.27	10.62	1.36	1.10	24.39	19.13	0.0020	3.96	4	
48	11.69	88.24	7.32	56.50	1.39	1.09	24.86	19.86	0.0471	22.93	4	
49	6.05	93.77	15.82	178.00	1.10	0.55	19.83	11.03	0.4006	50.66	4	
50	2.11	97.68	24.50	3.62	0.86	0.39	15.75	7.47	1.2189	80.15	4	

It will be seen by the above table that the tests by torsional stress confirmed the results obtained by the tests by transverse and tensile stresses, and also those obtained from the tests of the first series.

The maximum strength is given by No. 34 (82.72 copper, 17.33 tin). There is a rapid decrease of strength from No. 35 (77.56 copper, 22.25 tin) to No. 36 (72.89 copper, 26.85 tin), and then a much slower decrease to No. 40 (53.46 copper, 46.54 tin), the weakest of the series. From this point to No. 46 (21.60 copper, 77.58 tin) there is a slow and somewhat irregular increase up to a second maximum, and from No. 46 to the end of the series another decrease to the second minimum.

Referring to the autographic strain diagrams and the appended tables, in connection with the above table of average results, the following observations may be made on the tests of the pieces from each bar:

No. 31, Plate LIV (99.09 copper, 0.87 tin).—Four pieces were tested, all of which were defective in consequence of blow-holes and the separation of the metals. The results are therefore rejected in the table of final summary of results (Table —) and from the curves of strength of the series. The fractures were copper-red, only two small spots of a yellowish alloy being found in one of them. The turned surfaces showed the same appearance which was noted under the tensile test, viz, a number of yellowish spots scattered at intervals over the otherwise uniformly copper-colored surface, indicating a separation either into two alloys, or into copper and one alloy. Its strength is very much less than that of the copper piece, No. 30, and nearly the same as that of the copper, No. 1, which was oxidized and full of blow-holes.

No. 32, Plates LIV, LV, LVI (94.10 copper, 5.43 tin).—The four pieces tested were all fair specimens and gave results which are nearly alike, the maximum torsional movement varying from 150 to 165 foot-pounds, and the angles of torsion from 153 to 207 degrees. The fractures were all similar, being of a yellowish-red color and earthy structure, and containing a few very small blow-holes.

The effect of long-continued stress was tried in the torsion tests of three pieces of No. 32, lettered A, B, C. No. 32 A was left under stress 15 minutes, and No. 32 B one hour. In each of these cases no change of the shape of the diagram could be detected, the pencil remaining in the position in which it was left during the whole time. No. 32 C was left for 26 hours, after it had been twisted through more than 100 degrees. In that time the pencil fell less than one-tenth of an inch, indicating a decrease of resistance of about 5 per cent. of the maximum stress. On resuming the test, the diagram rose again to just beyond its original height.

No. 33, Plates LVII, LVIII (88.40 copper, 11.59 tin).—The four pieces tested gave results closely agreeing with each other, showing a somewhat greater strength and a much less ductility than No. 32. The fractures were similar in color and texture to those by tensile stress. No. 33 D was left under stress for 15 hours without showing any fall in the diagram. On resuming the test the line retained the same direction it had before, thus showing no decrease of resistance with time.

No. 34, Plate LVIII (82.72 copper, 17.33 tin).—Four pieces were tested, the average result showing the highest strength of the series, thus confirming the results shown by the transverse and tensile tests. The ductility was very much less than that of No. 33, the average angle of torsion being only 14 degrees. The fractures were of a pinkish-gray color and granular structure. All of the fractures showed some dark brownish-yellow spots in the center, indicating a want of homogeneity, and possibly a lateral separation of the metals.

No. 35, Plate LVIII (77.56 copper, 22.25 tin).—Four pieces were tested, giving results which varied considerably, the torsional moment of No. 35 B being 215 foot-pounds, and that of No. 35 C 104 foot-pounds. The lower strength of No. 35 C and No. 35 D may possibly be accounted for by the method of making the tests, as with these pieces a special experiment was made with the machine to determine the character of the diagram made by a very rapid motion while a brittle piece was under stress. The effect is seen in the curvature toward the horizontal of the diagram of No. 35 C, and in the irregularity of the diagram of No. 35 D. The average result of the four tests shows a considerably less strength than that of No. 34, as was also shown by the tensile and transverse tests.

The fractures were all similar in appearance, being of a light-gray color and very fine granular structure.

No. 36, Plate LIX (72.89 copper, 26.85 tin).—Two pieces only were tested from this bar. It was so hard and brittle that it could not be turned in the lathe without danger of breaking. The torsion pieces were therefore shaped by grinding on an emery wheel, as were those from No. 37 to No. 41. They were ground merely to a circular section of a little less than one inch in diameter. The strength as obtained from the diagram is reduced to equivalent strength of a piece of standard size (0.625 inch diameter) by dividing by the ratio of the cube of the diameter of the piece tested to the cube of 0.625.

The two pieces from bar No. 36 gave nearly similar results, the strength being less than one-fourth of that of the average of No. 35. The diagrams, like all those of brittle materials, are almost straight lines slightly inclined from the vertical. The fractures are of a very light pinkish-gray color, and show some appearance of radiated laminæ similar to the fractures by transverse and tensile stresses.

No. 37, Plate LIX (67.87 copper, 32.09 tin).—Two pieces were tested which gave considerably less strength than No. 36. The fractures were brilliant silver white, vitreous and conchoidal.

No. 38, Plate LIX (62.42 copper, 37.48 tin).—Two pieces were tested, one from the bottom and one from the top, which gave widely different results. No. 38 A showed a torsional strength of 35.44 foot-pounds of moment (when reduced to the standard), which is nearly that of the average of the pieces from No. 36. The fracture was almost precisely similar to that of No. 37. No. 38 B gave only 2.95 foot-pounds torsional moment, which is much lower than that of any piece yet noted. Its fracture showed it to be an entirely different metal from No. 38 A, being dark gray in color and stony in structure, closely resembling in appearance the fracture of No. 12 (62.31 copper, 37.35 tin) of the first series, the bar of maximum density as before described. It was not, however, perfectly homogeneous in color, some portions being of a lighter shade of gray than others and less brilliant.

The liquation of the metals in this bar has already been noticed, and the torsion tests fully confirm the record of the tests by tension, No. 38 B showing the lowest tensile strength of the series. The average of the two results gives a strength less than that of No. 37 and greater than that of No. 39, thus making no irregularity in the table of averages, given above.

No. 39, Plate LIX (57.87 copper, 42.05 tin).—Only one piece was tested from this bar, the other pieces having been broken in turning or shaping on the emery wheel. Its strength was much less than the average of the two pieces of No. 38. The fracture was of a light-gray color, with a stony structure, and with radiated lines of cooling.

No. 40, Plate LIX (53.46 copper, 46.54 tin).—Two pieces were tested, giving an average strength less than that of No. 39, and the lowest of the series. The fractures were scarcely distinguishable from that of No. 39.

No. 41, Plate LIX (47.27 copper, 52.72 tin).—Two pieces were tested, giving results nearly alike, the average being much higher than that of No. 40. The fractures were very similar to those of No. 39 and No. 40.

No. 42, Plate LIX (43.99 copper, 55.91 tin).—Three pieces were tested, which differed considerably in strength, the pieces A, B, and C giving torsional moments of 20.84, 16.11, and 11.75 foot-pounds, respectively. The average is less than that of No. 41, making an irregularity in the table of averages. The weakness of the pieces No. 42 B and No. 42 C seems to be caused by a difference in structure, the fractures of these pieces showing confusedly radiated laminæ, while that of No. 42 A is compact and stony, similar to that of No. 41. The difference in strength and appearance is fully accounted for by the analyses, which show that a great amount of liquation took place in the casting of this bar, the composition of top and bottom varying more than 20 per cent.

No. 43, Plate LIX (37.10 copper, 62.90 tin).—Four pieces were tested, the metal being soft enough to be turned in the lathe to pieces of standard size. The strength was quite irregular, and the average was less than that of No. 42. The fractures were of a light-gray color, with large radiated prismatic crystals.

No. 44, Plate LX (30.76 copper, 69.19 tin).—Four pieces were tested, which gave results widely varying. No. 44 A had a maximum torsional moment of only 683 foot-pounds, and No. 44 B a moment of 30.29 foot-pounds. The average of the four pieces was much higher than that of No. 43. The fractures were all crystalline, the crystals of No. 44 A being much larger than those of the other pieces. From the fact that the torsion pieces from the upper end of each of the bars, Nos. 44, 45, 46, and 47, were weaker than those of the other pieces from the same bars, it appears probable that the weakness is due either to difference in pressures of the molten metal at the top and bottom of the mold, or to differences in the rate of cooling, or possibly to both. This irregularity of strength of all the white crystalline alloys has been noted already in the tests of the first series.

No. 45, Plate LX (26.62 copper, 73.18 tin).—Three pieces were tested, showing considerable irregularity in strength, No. 45 A having less than half of the strength of No. 45 C. The fractures were irregularly laminated and crystalline. The average strength was much higher than that of No. 44, showing the approach to the second maximum of strength.

No. 46, Plate LX (22.10 copper, 77.58 tin).—Four pieces were tested, giving an average strength greater than that of No. 45, and showing the point of second maximum strength of the series, which confirms the tests by transverse stress. The piece No. 46 A had a much less strength than either of the other pieces, but it does not affect the average sufficiently to place it below the second maximum. The fractures were similar to those of No. 45.

No. 47, Plate LX (16.70 copper, 83.23 tin).—Four pieces were tested, giving a somewhat less strength than No. 46. The piece No. 47 A had only 17.35 foot-pounds torsional moment, while the pieces B, C, and D had 27.59, 25.03, and 27.59 pounds, respectively. The fractures were largely granular in the center and laminated at the edges.

No. 48, Plate LXI (11.68 copper, 88.25 tin).—Four pieces were tested, which all gave results agreeing very closely. The average strength of the four pieces is a little higher than that of No. 47, but less than that of the three pieces of No. 47 marked B, C, D. The slight irregularity in the decrease of strength of the series from No. 46 to No. 50 is due, therefore, entirely to the exceptional weakness of No. 47 A. These pieces exhibited much greater ductility than No. 46. The fractures were in a plane perpendicular to the axis of the specimen, a characteristic of the torsional fractures of all ductile metals. They were of a light-gray color and fine granular structure.

No. 49, Plates LXI, LXII, LXIII (6.05 copper, 93.77 tin).—The four pieces gave an average strength considerably less than that of No. 48, confirming the law of gradual decrease toward the end of the series. They were very ductile, twisting through angles of from 125 to 221 degrees before breaking. The turned surfaces became much distorted and the plane surfaces of fracture were polished by rubbing together as rupture took place.

No. 50, Plates LXIV, LXV, LXVI, LXVII (2.11 copper, 97.68 tin).—The average strength of the four pieces tested was less than that of No. 49, giving the point of second minimum strength of the series. The pieces were very ductile, twisting through 325 to 424 degrees. The turned surfaces and surfaces of fracture were similar to those of No. 49.

In testing some of the pieces of No. 49 and No. 50, experiments were made to show the effect of rapid and of slow motion, and of leaving under stress for a length of time, with the same results as were shown in the tests by torsion of the ductile metals of the first series, and also by the tensile and transverse tests, viz, the increase of resistance to rapid motion, and the decrease of resistance on being left under stress for a time. The diagrams show very plainly the results of these "time tests."

TESTS BY COMPRESSION.

The pieces were carefully prepared, like those of the first series, of a uniform size of 2 inches in height and 0.625 inch in diameter, with their ends made plane surfaces perpendicular to the axis. The tests were made in the machine (Fig. 6, p. 292), to which an attachment had been added for the purpose. The measurements were made with great accuracy by means of the apparatus (Fig. 13) described on page 326. It was found that the point and moment of contact could be determined more rapidly and with even greater accuracy by connecting a battery and signal and letting the contact of the end of the micrometer-screw complete the circuit.

Tables are appended giving the results of the test of each bar, and the following table (Table X*a*) presents a summary of all results of these tests of alloys, and also of several extra bars of cast copper:

TABLE X*a*.—SECOND SERIES—ALLOYS OF COPPER AND TIN.

Tests by Compressive Stress.

Number.	Composition by analysis.		Load per square inch causing a compression of—			Maximum load per sq. inch.	Total compression produced by maximum load. Parts of original length.	Crushing strength per square inch.	Remarks.
	Copper.	Tin.	5 per cent.	10 per cent.	20 per cent.				
			Pounds.	*Pounds.*	*Pounds.*	*Pounds.*		*Pounds.*	
31	99.09	0.87	32,500	42,000	52,000	81,485	.4400	42,000	
32	94.11	5.43	39,000	46,000	65,000	130,379	.4665	46,000	
33	88.40	11.59	45,000	58,670	91,266	143,417	.3455	58,670	
34	82.72	17.33	84,000	104,000	136,898	143,417	.1910	104,303	
35	77.56	22.25	130,379	149,932	....	149,932	.1013	149,932	
43	37.10	62.90	....	....	....	6,519	.0025	6,519	Cracked.
44	30.76	69.19	....	....	....	16,297	.0040	16,297	Crushed.
45	26.62	73.18	....	....	....	16,297	.0091	16,297	Do.
46	22.10	77.58	....	....	....	16,207	.0113	16,297	
47	16.70	83.23	....	....	....	9,778	.0025	9,778	
48	11.68	88.25	....	......	....	13,038	.0305	13,038	
51 B	Cast copper.		30,000	36,000	50,000	104,303	.5154	36,000	Flattened.
52	do		30,000	37,000	50,000	91,266	.4814	37,000	Do.
53	do		35,000	48,000	65,000	97,785	.4122	48,000	Do.

The following observations were noted in connection with the individual tests. The manner in which they yielded under the pressures applied to them is shown in Plate XXI, and a record and comparison of all results of both series is given by the curves of Plate IV.

The increments of pressure upon the test-pieces were 1,000 pounds for the weaker alloys and 2,000 for the stronger, which for a diameter of 0.625 correspond respectively to pressures of 3,259 and 6,519 pounds per square inch.

No. 31 (99.09 copper, 0.87 tin).—A comparison of the plotted curves of Nos. 31 and 1 (copper) shows much similarity, with an increased resistance to compression on the part of No. 31. The test was ended at a pressure of 81,485 pounds per square inch by the cracking of a wedge-shaped piece at the top and a similar one at the bottom. The compression at this point was 0.8801 inch. The piece was considerably bent. The diameter of its oval section varied from 0.79 to 0.84 inch.

No. 32 (94.11 copper, 5.43 tin).—The compression of the piece was not measurable until it had been subjected to a pressure of 19,557 pounds per square inch, which caused a compression of 0.0001 inch. At 26,075 pounds per square inch the compression was 0.0108 inch, its *apparent* elastic limit, as shown by the curve, being near this pressure. The piece was removed after being subjected to a pressure of 130,379 pounds per square inch, which caused a compression of 0.9330 inch. It was much bent. It had none but mere surface cracks. Its section was slightly oval, with diameters varying from 0.80 to 0.86 inch.

No. 33 (88.40 copper, 11.59 tin).—The *apparent* elastic limit was at about 30,000 pounds per square inch. Under a pressure of 32,595 pounds per square inch the compression was 0.0374 inch. Beyond this point the amount of compression continued very nearly proportional to the pressure until a compression of 0.6911 inch under a pressure of 143,417 pounds per square inch was reached, when the piece was removed. The specimen was bent, the surface quite uniformly mottled or wrinkled, but showed no sign of fracture, and would evidently have resisted a considerably greater pressure and compression. Its section was nearly circular and had increased to a diameter of from 0.72 to 0.74 inch.

No. 34 (82.72 copper, 17.33 tin).—The first point at which a marked change in the direction of the plotted curve can be observed is at the pressure of 58,671 pounds per square inch, which gave a compression of 0.0268 inch. A pressure of 71,709 pounds per square inch caused a compression of 0.0628 inch. From this point to the end of the test the compressions, as shown by the curve, were proportional to the pressures. The greatest compression obtained was 0.3821 inch, caused by a pressure of 136,898 pounds per square inch. A pressure of 143,417 pounds per square inch caused a wedge, whose base was the full size of the diameter of the piece, to separate from the top, the pressure upon the surfaces as they slid upon each other burnishing them. A semi-cylindrical piece about 0.4 inch in height flew off from the bottom. Cracks extended upward to the middle. The piece was but slightly bent. The diameter had increased to from 0.67 to 0.69 inch.

No. 35 (77.56 copper, 22.25 tin).—This piece proved to be the strongest of either series. It withstood pressures up to 91,260 pounds per square inch and a compression of 0.0190 inch before the ratio of compression to pressure began to increase and to show that the *apparent* limit of elasticity had been passed. The piece, however, withstood, without yielding, the utmost pressure that could be brought to bear upon it by the testing machine. The maximum compression was 0.2027 inch, produced by a pressure of 149,932 pounds per square inch. The surface was slightly wrinkled and showed a few surface cracks. A bend could be just distinguished. The section remained circular and measured 0.69 inch in diameter.

No. 36 (72.89 copper, 26.85 tin) to No. 42 (43.99 copper, 55.91 tin) gave no definite results, as they crumbled under slight pressure.

No. 43 (37.10 copper, 69.19 tin).—This piece was weak and brittle. A pressure of 6,519 pounds caused a compression of 0.0051 inch. On adding the next weight, which brought to bear a pressure of 13,038 pounds per square inch, the bottom crumbled into fragments. The upper portions were unchanged in appearance or size.

No. 44 (30.76 copper, 69.19 tin) behaved in the same manner as No. 43. It was somewhat stronger, sustaining a pressure of 13,038 pounds per square inch and a corresponding compression of 0.0081 inch. A pressure of 16,297 pounds per square inch was brought upon it, which it resisted just long enough to hit the scale-beam, when it yielded by pieces breaking from the top. The surface presented a slightly wrinkled appearance and the diameter was increased to 0.61 inch.

No. 45 (26.62 copper, 73.18 tin) was similar to No. 44, but somewhat more yielding, a pressure of 13,038 pounds compressing it 0.0182 inch. A pressure of 16,297 pounds per square inch had just raised the scale-beam, when pieces broke from the middle of the specimen. The diameter and the appearance of the remaining portion was unchanged.

No. 46 (22.10 copper, 77.58 tin) behaved much like Nos. 44 and 45, but showed a little more ductility. A pressure of 13,038 pounds per square inch caused a compression of 0.0227 inch. It was crushed by a pressure of 16,297 pounds, which forced off wedge-shaped pieces near the bottom. The upper portion of the specimen was not changed in diameter or appearance.

No. 47 (16.70 copper, 83.23 tin) was weak and brittle; a pressure of 6,519 pounds per square inch caused a compression of 0.0051 inch. Under a pressure of 9,788 pounds per square inch wedge-shaped pieces broke out from the middle.

No. 48 (11.68 copper, 88.25 tin).—This piece was very weak, but less brittle than the four preceding specimens. A pressure of 9,778 pounds per square inch compressed it 0.0611 inch. A pressure of 13,038 pounds per square inch caused it to yield in three portions; the top and bottom parts being wedge-shaped, with the points of the wedges meeting and having bases the full size of the diameter of the specimen, and the remaining or middle portion being in one piece, and the whole welded together.

No. 51 (cast copper).—A pressure of 19,557 pounds per square inch caused a compression of 0.0089 inch. A pressure of 26,075 pounds per square inch caused a compression of 0.0573 inch. The change in the curve which seemed to mark the elastic limit occurs between these two. Beyond the last-named observation, and until the piece was removed, the ratio of compression to pressure continued nearly constant, as is shown by the plotted record, which is nearly a straight line up to the point corresponding to a pressure of 71,705 pounds per square inch, where an increase of resistance is observed. The maximum pressure was 104,303 pounds per square inch and the maximum compression was 1.0308 inch.

No. 52 (cast copper) offered a resistance very similar to No. 51. The apparent elastic limit was between the same pressures. The pressure was carried up to 91,266 pounds per square inch, causing a compression of 0.9628 inch. The piece flattened and bent considerably. The section was oval, and the diameters varied from 0.84 to 0.91 inch.

No. 53 (cast copper) showed greater resistance to compression than either Nos. 51 and 52. A change in direction of the plotted curve occurs at the same pressures as noted in the last-named tests, but it is not marked, the line showing a gradual curve up to 55,000 pounds per square inch. The maximum pressure applied was 97,785 pounds per square inch, and the compression caused by that pressure was 0.8244 inch.

ANALYSES AND SPECIFIC GRAVITIES.

The following tables give the results of the chemical analyses and determinations of specific gravity which were made of portions of each bar tested, in both the first and second series.

The analyses were made from the turnings and chips made in shaping the specimens for test by tensile stress, two samples for analysis being thus taken from each bar. In some cases in which liquation was plainly seen from the appearance of the fracture, analyses were made of three portions of the bar.

The specific gravity determinations were made of pieces weighing from 50 to 75 grammes, taken from the cylindrical portion of the broken tensile-test pieces. The pieces of the more ductile specimens were taken from the portion of the test-piece farthest from the point of fracture, and therefore least distorted by the stress. Care was taken to secure pieces as free from blow-holes as possible, but in some cases this could not be done, and the results are therefore too low, as those which are indicated in the tables by an asterisk.

In determining the specific gravities, the pieces were first washed in alcohol to free them from any dirt or grease which might be attached to them, and then thoroughly dried. The weighings were made on a Becker & Son's chemists' balance, which was sensitive to $\frac{1}{10}$ of a milligramme. Before weighing in water, the pieces were boiled for two or three hours, to remove as far as possible the air inclosed in the pores of the metal, and after cooling in the dish in which they were boiled they were placed under the receiver of an air-pump, and the air was further exhausted. They were then rapidly transferred to the beaker of distilled water, in which they were weighed, being suspended by a loop of very fine platinum wire from the arm of the balance. The water in which they were weighed was always kept at the same level, and the proper correction was made for the weight of the platinum wire.

The results given in the table are corrected for the temperature of the water, being reduced to the standard of water of maximum density (39°.1 Fahr.).

It will be seen that the bars which have been described under the remarks on the tests as being full of blow-holes give low specific gravities, and it seems probable that all the figures of all the bars, from No. 1 to No. 9 and No. 30 to No. 34, are lower than the true specific gravities of the metal.

To determine the effect of the porous structure in reducing the apparent specific gravity, a special determination was made of No. 6 A (87.15 copper, 12.69 tin) in the shape of turnings. It will be remembered that the test specimen with this number showed a separation of the metals into two distinct alloys, which appeared intimately mixed in the fractured surface. The piece whose specific gravity was determined to be only 8.408 as given in the tables, was apparently free from blow-holes of any appreciable size, but the fracture had a porous appearance. Five turnings were made from the same piece, and their density was determined by the specific-gravity bottle, and also by weighing them in water in a small dish of platinum foil suspended from the arm of the balance. Considerable difficulty was experienced in removing the air-bubbles, and it was only after several boilings and exhaustions with the air-pump that constant weighings were obtained, the apparent specific gravity increasing as the air was more perfectly removed. The result finally obtained was a density of 8.943, corrected for the expansion of water, and this figure was obtained by both methods.

The density of turnings from the ingot-copper used in making the alloys was in like manner determined to be 8.874.

A marked difference is seen between the density of the copper bar No. 1 and that of No. 30, which corresponds to their difference in other properties.

In averaging the figures obtained for the column of mean specific gravity, Nos. 2 A, 6 A, and 31 A are rejected, as the figures obtained for them are evidently much lower than their true specific gravities.

The bars which exhibited liquation also show a great difference in specific gravity in the top and bottom of the bar, corresponding to the difference in composition.

In bar No. 38 (62.42 copper, 37.48 tin), the mean specific gravity is taken to be that of the piece from the middle of the bar No. 38 C, as the composition of this piece agrees more nearly than the other portions of the bar with the original mixture, and this composition nearly corresponds to the maximum density shown by No. 12.

TABLE XI.—FIRST SERIES—ALLOYS OF COPPER AND TIN.

Analyses and Specific Gravities.

Number.	Original mixture.		Analysis.		Variation of composition.		Mean analysis.		Specific gravity.	Mean specific gravity.
	Copper.	Tin.	Copper.	Tin.	Copper.	Tin.	Copper.	Tin.		
1 A	100.00	0.00	....	....	....	....	....	....	....	8.487*
B	100.00	0.00	....	....	....	....	....	....	8.487*	
2 A	98.10	1.90	97.95	1.88	— 0.15	— 0.02	97.89	1.90	8.092*	8.564
B	98.10	1.95	97.83	1.92	— 0.27	+ 0.02			8.564	
3 A	96.27	3.73	96.16	3.71	— 0.11	— 0.02	96.06	3.76	8.699	8.649
B	96.27	3.73	95.96	3.80	— 0.31	+ 0.07			8.599	
4 A	92.80	7.20	92.14	7.84	— 0.56	+ 0.64	92.11	7.80	8.668	8.694
B	92.80	7.20	92.07	7.76	— 0.73	+ 0.56			8.720	
5 A	90.00	10.00	90.11	9.66	+ 0.11	— 0.34	90.27	9.58	8.635	8.669
B	90.00	10.00	90.43	9.50	+ 0.43	— 0.50			8.703	
6 A	86.57	13.43	87.15	12.69	+ 0.58	— 0.74	87.15	12.73	8.408*	8.681
B	86.57	13.43	87.15	12.77	+ 0.58	— 0.66			8.681	
7 A	80.00	20.00	80.99	18.92	+ 0.99	— 1.08	80.95	18.84	8.759	8.740
B	80.00	20.00	80.90	18.75	+ 0.90	— 1.25			8.721	
8 A	76.32	23.68	76.67	23.24	+ 0.35	— 0.44	76.64	23.24	8.558*	8.565*
B	76.32	23.68	76.60	23.23	+ 0.28	— 0.45			8.572*	
9 A	70.00	30.00	69.90	29.85	— 0.10	— 0.15	69.84	29.89	8.935	8.932
B	70.00	30.00	69.77	29.92	— 0.23	— 0.08			8.928	
10 A	68.25	31.75	68.59	31.21	+ 0.34	— 0.54	68.58	31.26	8.938	8.938
B	68.25	31.75	68.57	31.30	+ 0.32	— 0.45			8.937	
11 A	65.00	35.00	65.31	34.47	+ 0.31	— 0.53	65.34	34.47	8.924	8.947
B	65.00	35.00	65.36	34.47	+ 0.36	— 0.53			8.965	
12 A	61.71	38.29	61.83	37.74	+ 0.12	— 0.55	62.31	37.35	8.971	8.970
B	61.71	38.29	62.79	36.96	+ 1.08	— 1.33			8.969	
13 A	56.32	43.68	56.58	43.11	+ 0.26	— 0.57	56.70	43.17	8.728	8.682
B	56.32	43.68	56.82	43.22	+ 0.50	— 0.46			8.635	
14 A	51.80	48.20	62.27	37.58	+10.47	—10.62	51.62	48.09	8.944	8.560
C	51.80	51.80	38.41	61.04	—13.39	+12.84			8.202	
B	51.80	48.20	51.62	48.09	— 0.18	— 0.11			8.533	
15 A	47.95	52.05	47.72	51.99	— 0.23	— 0.06	47.61	52.14	8.462	8.442
B	47.95	52.05	47.49	52.29	— 0.46	+ 0.24			8.422	
16 A	44.63	55.37	44.62	55.15	— 0.01	— 0.22	44.52	55.28	8.395	8.312
B	44.63	55.37	44.42	55.41	— 0.21	+ 0.04			8.229	
17 A	41.74	58.26	45.93	53.80	+ 4.19	— 4.46	42.38	57.30	8.523	8.302
B	41.74	58.26	38.83	60.79	— 2.91	+ 2 53			8.081	
18 A	39.20	60.80	43.37	56.37	+ 4.17	— 4.43	38.37	61.32	8.160	8.182
C	39.20	39.20	38.37	61.32	— 0.83	+ 0.52			......	
B	39.20	60.80	43.36	56.40	+ 4.16	— 4.40			8.203	
19 A	34.95	65.05	40.32	59.46	+ 5.37	— 5.59	34.22	65.80	8.036	8.013
C	34.95	34.95	34.22	65.80	— 0.73	+ 0.75			......	
B	34.95	65.05	40.24	59.44	+ 5.29	— 5 61			7.989	
20 A	28.72	71.28	26.57	73.08	— 2.15	+ 1.80	25.85	73.80	7.956	7.948
B	28.72	71.28	25.12	74.51	— 3.60	+ 3.23			7.940	
21 A	24.38	75.62	22.80	76.89	— 1.58	+ 1.27	23.35	76.29	7.813	7.835
B	24.38	75.62	23.89	75.68	— 0.49	+ 0.06			7.856	
22 A	21.18	78.82	20.28	79.63	— 0.90	+ 0.81	20.25	79.63	7.757	7.770
B	21.18	78.82	20.21	79.62	— 0.97	+ 0.80			7.783	
23 A	15.19	84.81	15.12	84.58	— 0.07	— 0.23	15.08	84.62	7.669	7.657
B	15.19	84.81	15.04	84.65	— 0.15	— 0.16			7.644	
24 A	11.84	88.16	11.49	88.44	— 0.35	+ 0.28	11.49	88.47	7.521	7.553
B	11.84	88.16	11.48	88.50	— 0.36	+ 0.34			7.582	
25 A	9.70	90.30	8.82	91.12	— 0.88	+ 0.82	8.57	91.39	7.515	7.487
B	9.70	90.30	8.32	91.66	— 1.38	+ 1.36			7.459	
26 A	4.29	95.71	3.70	96.30	— 0.59	+ 0.59	3.72	96.31	7.401	7.360
B	4.29	95.71	3.74	06.32	— 0.55	+ 0.61			7.318	
27 A	1.11	98.89	0.75	98.98	— 0.36	+ 0.09	0.74	99.02	7.311	7.305
B	1.11	98.89	0.72	99 06	— 0.39	+ 0.17			7.299	
28 A	0.557	99.443	0.32	99.46	— 0.237	+ 0.017	0.32	99.46	7.299	7.299
B	0.557	99.443	0.32	99.45	— 0.237	+ 0.007			7.299	
29 A	0.00	100.00	....	....	....	....	....	....	7.297	7.293
B	0.00	100.00	....	....	....	....	....	....	7.289	
30 A	100.00	0.00	....	....	....	....	....	....	8 797	8.791
B	100.00	0.00	....	....	....	....	....	....	8.785	

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*The figures marked with a star in the columns of specific gravities are much lower than the true specific gravities, in consequence of the presence of blow-holes. The specific gravity of No. 6 A was re-determined in the shape of fine turnings, and found to be 8.943. A determination of the specific gravity of fine turnings of the ingot-copper used in this series was also made, giving the result 8.874.

TABLE XII.—SECOND SERIES—ALLOYS OF COPPER AND TIN.

Analyses and Specific Gravities.

Number.	Original mixture.		Analysis.		Variation of composition.		Mean analysis.		Specific gravity.	Mean specific gravity.
	Copper.	Tin.	Copper.	Tin.	Copper.	Tin.	Copper.	Tin.		
31 A	97.5	2.5	99.40	0.52	+1.90	—1.98	99.09	0.87	8.511	8.511
B	97.5	2.5	98.79	1.22	+1.29	—1.28			*8.251	
32 A	92.5	7.5	93.98	5.47	+1.48	—2.03	94.11	5.43	8.704	8.684
B	92.5	7.5	94.23	5.39	+1.73	—2.11			8.664	
33 A	87.5	12.5	88.35	11.61	+0.85	—0.89	88.41	11.59	8.650	8.648
B	87.5	12.5	88.46	11.57	+0.96	—0.93			8.645	
34 A	82.5	17.5	82.72	17.33	+0.22	—0.17	82.70	17.34	8.794	8.792
B	82.5	17.5	82.69	17.34	+0.19	—0.16			8.789	
35 A	77.5	22.5	77.41	22.27	—0.09	—0.23	77.56	22.25	8.935	8.917
B	77.5	22.5	77.71	22.23	+0.21	—0.27			8.899	
36 A	72.5	27.5	72.85	26.80	+0.35	—0.70	72.89	26.85	8.925	8.925
B	72.5	27.5	72.94	26.90	+0.44	—0.60			8.925	
37 A	67.5	32.5	67.66	32.82	+0.16	—0.28	67.87	32.10	8.914	8.907
B	67.5	32.5	68.08	31.98	+0.58	—0.52			8.900	
38 A	62.5	37.5	67.59	32.32	+0.509	—5.18	62.42	37.48	8.863	8.956
C	62.5	62.5	63.69	36.27	+1.19	—1.23			8.956	
B	62.5	37.5	55.99	43.85	—6.51	+6.85			8.744	
39 A	57.5	42.5	64.21	35.56	+6.71	—6.94	57.88	42.05	8.874	8.781
C	57.5	57.5	....	....	....	....			8.831	
B	57.5	42.5	51.54	48.54	—5.96	+6.04			8.637	
40 A	52.5	47.5	56.83	43.21	+4.33	—4.04	53.46	46.55	8.779	8.648
B	52.5	47.5	50.10	49.88	—2.40	+2.38			8.507	
41 A	47.5	52.5	47.10	52.86	—0.40	+0.36	47.27	52.72	8.461	8.446
B	47.5	52.5	47.43	52.59	—0.07	+0.09			8.430	
42 A	42.5	57.5	55.21	44.80	+12.71	—12.70	43.99	55.91	8.461	8.437
B	42.5	57.5	32.77	67.02	—9.73	+9.52			8.412	
43 A	37.5	62.5	37.62	62.36	+0.12	—0.14	37.10	62.90	8.112	8.101
B	37.5	62.5	36.58	63.44	—0.92	+0.94			8.090	
44 A	32.5	67.5	33.86	66.01	+1.36	—1.49	30.76	69.19	7.931	7.931
B	32.5	67.5	27.66	72.37	—4.84	+4.87			7.776	
45 A	27.5	72.5	26.64	73.15	—0.86	+0.65	26.63	73.17	7.945	7.915
B	27.5	72.5	26.61	73.20	—0.89	+0.70			7.885	
46 A	22.5	77.5	22.09	77.62	—0.41	+0.12	22.10	77.58	7.807	7.774
B	22.5	77.5	22.11	77.54	—0.39	+0.04			7.741	
47 A	17.5	82.5	16.74	83.11	—0.76	+0.61	16.70	83.23	7.685	7.690
B	17.5	82.5	16.66	83.36	—0.84	+0.86			7.695	
48 A	12.5	87.5	11.67	88.25	—0.73	+0.75	11.69	88.24	7.549	7.543
B	12.5	87.5	11.70	88.24	—0.80	+0.74			7.536	
49 A	7.5	92.5	6.07	93.75	—1.43	+1.25	6.05	93.77	7.403	7.417
B	7.5	92.5	6.03	93.79	—1.47	+1.29			7.430	
50 A	2.5	97.5	2.18	97.60	—0.32	+0.10	2.11	97.68	7.339	7.342
B	2.5	97.5	2.03	97.77	—0.47	+0.27			7.344	

GENERAL SUMMARY OF RESULTS.

The following table exhibits a condensed summary of results of all the tests which have been made in both series arranged in the order of their composition by original mixture.

The results under the heads of "Tests by tensile stress" and "Tests by torsional stress" are the averages of the results of the tests of the two or four specimens bearing the same numbers, but in all cases rejecting tests of defective specimens except bar No. 1, which is retained for comparision with bar No. 30.

TABLE XIII.—FIRST AND SECOND SERIES—ALLOYS OF COPPER AND TIN.

Summary of Average Results.

Number.	Atomic proportion.	Composition of original mixture.		Mean composition by analysis.		Mean specific gravity.	Tests by transverse stress.					Tests by tensile stress.					Compression tests.		Tests by torsional stress.				
		Copper.	Tin.	Copper.	Tin.		Modulus of rupture.	Elastic limit, in parts, of breaking load.	Total deflection before breaking.	Resilience within a deflection of 3¼ inches.	Modulus of elasticity.	Tensile strength per sq. inch of—		Elastic limit, percentages of breaking load.	Total elongation, in parts of original length.	Diameter of fractured section, percentages of original.	Crushing strength, pounds per square inch.	Amount of compression, percentages of original length.	Torsional moment.		Ductility.		Resilience.
												Original section.	Fractured section.						Maximum.	Elastic limit, percentages of maximum.	Angle of torsion.	Extension of exterior fiber.	
									Inch's	*Ft.lbs.*		*Pounds.*	*Pounds.*						*Foot-lbs.*				
1*	Cu	100.00	0.00	...	...	‡8.487	21,251	.346	2.306	114.8	13,986,605	12,760	12,987	.862	.0047	.96	39,000	.10+	65.66	.505	40.50	0.0255	37.71
30	Cu	100.00	0.00	...	...	8.791	29,848	.140	Bent	191.25	10,203,205	27,800	32,496	.518	.0647	.92	42,000	.10+	143.24	.353	153.00	0.3084	320.35
2	$SnCu_{96}$	98.10	1.90	97.89	1.90	8.564	...	...	...	...	...	...	...	...	...	...	34,000	.10+	150.46	.248	317.50	1.0006	572.51
31*		97.50	2.50	99.09	0.87	8.511	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
3	$SnCu_{48}$	96.27	3.73	96.06	3.76	8.649	33,232	.350	Bent	239.68	13,739,654	32,000	42,692	.500	.1429	.86	42,000	.10+	156.93	.338	247.40	0.7031	599.96
4	$SnCu_{24}$	92.80	7.20	92.11	7.80	8.694	43,731	.426	Bent	310.58	14,263,420	28,540	33,780	.666	.0553	.92	42,000	.10+	160.01	.383	125.00	0.2189	277.22
32		92.59	7.50	94.11	5.43	8.684	38,659	.370	Bent	264.20	13,581,817	27,900	34,383	.502	.0742	.88	...	...	156.68	.333	187.25	0.4318	368.33
5		90.00	10.00	90.27	9.58	8.669	49,400	.400	Bent	345.01	14,012,135	26,860	30,205	.586	.0366	.93	38,000	.10+	175.28	.414	114.50	0.1795	274.60
33		87.50	12.50	88.41	11.50	8.648	60,403	.353	4.000	415.14	12,472,655	31,100	33,153	.675	.0356	.97	...	...	178.05	.385	70.75	0.0730	175.23
6†	$SnCu_{12}$	86.57	13.43	87.15	12.73	‡8.681	...	...	2.291	155.70	...	29,430	30,680	.080	.0333	.98	53,000	.10+	182.32	.446	100.00	0.1391	253.61
34		82.50	17.50	82.70	17.34	8.792	67,930	.565	0.625	57.75	15,152,664	36,200	36,346	...	.0071	1.00	...	...	198.06	.516	14.00	0.0032	35.85
7		80.00	20.00	80.95	18.84	8.740	56,715	.657	0.492	44.30	13,304,198	32,980	32,980	...	.0040	1.00	78,000	.10+	190.15	.623	16.30	0.0040	35.59
35		77.50	22.50	77 56	22.25	8.917	29,926	1.00	0.161	5.62	15,149,535	24,650	24,630	1.00	.0054	1.00	...	...	153.96	.714	4.38	0.0003	6.46
8	$SnCu_{6}$	76.32	23.68	76.64	23.24	8.565	32,210	1.00	0.191	8.17	13,495,122	22,010	22,010	1.00	...	1.00	114,081	.0905	122.13	1.00	3.40	0.0002	3.72
36		72.50	27.50	72.89	26.85	8.925	9,512	1.00	0.048	0.57	16,387,041	6,493	6,493	1.00	...	1.00	...	...	35.54	1.00	1.00	0.00003	0.89
9		70.00	30.00	69.84	29 89	8.932	12,076	1.00	0.062	0.97	15,321,736	5,585	5,585	1.00	...	1.00	146,676	.0350	17.58	1.00	1.50	0.00008	0.63
10	$SnCu_{4}$	68.25	31.75	68.58	31.26	8.938	9,192	1.00	0.043	0.58	15,694,556	1,620	1,620	1.00	...	1.00	...	...	...	...	...	...	...
37		67.50	32.50	67.87	32.10	8.907	9,477	1.00	0.052	0.58	14,896,691	2,536	2,536	1.00	...	1.00	...	...	26.13	1.00	1.65	0.00009	1.08
11		65.00	35.00	65.34	34.47	8.947	4,776	1.00	0.020	0.12	19,344,368	2,201	2,201	1.00	...	1.00	84,747	.0285	16.44	1.00	0.75	0.00002	0.36
38		62.50	37.50	62.42	37.48	8.956	2,907	1.00	0.019	0.17	...	1,561	1,561	1.00	...	1.00	...	...	19.20	1.00	0.50	0.00001	0.15
12	$SnCu_{3}$	61.71	38.29	62.31	37.35	8.970	2,761	1.00	0.032	0.12	9,603,989	688	688	1.00	...	1.00	39,114	.0175	7.06	1.00	1.00	0.00003	0.25
39		57.50	42.59	57.88	42 05	8.781	3,732	1.00	0.021	0.12	...	1,377	1,377	1.00	...	1.00	...	...	8.60	1.00	0.50	0.00001	0.16
13	$Sn_{5}Cu_{12}$	56.32	43.68	56.70	43.17	8.682	2,120	1.00	0.010	0.01	14,693,518	1,455	1,455	1.00	...	1.00	...	...	8.94	1.00	1.00	0.00003	0.41
40		52.50	47.50	53.46	46.55	8.643	1,995	1.00	0.008	0.05	...	...	...	...	...	...	...	...	7.77	1.00	0.40	0.00001	0.08
14	$SnCu_{2}$	51.80	48.20	51.02	48.00	8.560	3,877	1.00	0.040	0.23	...	2,555	2,555	1.00	...	1.00	...	...	13.54	1.00	1.00	0.00003	0.19
15	$Sn_{7}Cu_{12}$	47.95	52.05	47.61	52.14	8.442	3,000	1.00	0.019	0.07	17,030,180	1,525	1,525	1.00	...	1.00	84,747	.0215	14.87	1.00	1.00	0.00008	0.28
41		47.50	52.50	47.27	52.72	8.446	5,601	1.00	0.019	0.18	...	2,407	2,407	1.00	...	1.00	...	...	17.96	1.00	1.00	0.00003	0.34
16	$Sn_{2}Cu_{3}$	44.63	55.37	44.52	55.28	8.312	4,770	1.00	0.026	0.15	16,823,869	3,010	3,010	1.00	...	1.00	35,854	.0066	23.85	1.00	0.92	0 00003	0.53
42		42.50	57.50	43.99	55.91	8.437	6,084	1.00	0.036	0.33	§9,824,600	2,098	2,098	1.00	...	1.00	...	...	16.23	1.00	1.33	0.00006	0.60

17	Sn_3Cu_4 ..	41.74	58.26	42.38	57.30	8.302	7,172	1.00	0.042	0.25	23,238,907	3,910	3,910	1.00	......	1.00	39,114	.0205	28.11	1.00	1.65	0.00007	0.60
18	Sn_5Cu_6 ...	39.20	60.86	38.37	61.32	8.182	8,400	1.00	0.060	0.46	12,302,353	2,820	2,820	1.00	.....	1.00	29,335	.0145	23.46	1.00	1.70	0.00005	0.42
43	....	37.50	62.50	37.10	62.90	8.101	6,942	.500	0.080	0.70	10,672,961	2,400	2,400	......	......	1.00	......	......	12.70	1.000	1.50	0.00004	0.20
19	Sn Cu.....	34.95	65.05	34.22	65.80	8.013	5,384	.625	0.043	0.25	11,041,901	3,371	3,371	......	.....	1.00	19,557	.0555	16.56	1.000	1.87	0.00005	0.31
44	....	32.50	67.50	30.76	69.19	7.931	7,178	.476	0.112	1.28	6,984,987	2,322	2,322	......	......	1.00	......	......	17.32	.977	2.63	0.00014	0.73
20	Sn_4Cu_3 ...	28.72	71.28	25.85	73.80	7.948	8,067	.583	0.121	1.53	9,982,832	1,648	1,648	......	......	1.00	17,927	.10+	20.97	1.000	2.34	0.00011	0.76
45	....	27.50	72.50	26.63	73.17	7.915	11,128	.438	0.220	3.69	7,803,107	4,380	4,380	......	.....	1.00	......	......	25.50	.985	3.17	0.00018	1.06
21	Sn_5Cu_3 ..	24.38	75.62	23.35	76.29	7.835	12,408	.378	0.209	5.33	11,520,262	6,775	6,775	......	......	1.00	......	......	41.50	.979	4.50	0.0003	2.25
46	....	22.50	77.50	22.10	77.58	7.774	13,687	.300	0.405	8.78	8,474,849	5,000	5,014	.....	.0022	1.00	......	......	27.80	.951	7.38	0.0012	3.31
22	Sn_2Cu	21.18	78.82	20.25	79.63	7.770	10,019	.333	0.345	5.35	9,743,644	4,337	4,337	......	......	1.00	16,297	.10+	22.93	.930	5.69	0.0006	2.07
47	....	17.50	82.50	16.70	83.23	7.690	10,288	.267	0.533	11.51	7,356,258	2,816	2,822	......	......	1.00	. .	....	21.39	.784	10.62	0.0020	3.96
23	Sn_3Cu	15.19	84.81	15.08	84.62	7.657	9,063	.222	0.858	12.89	7,032,130	6,520	6,520	.844	.0067	1.00	6,519	.10+	22.80	.753	24.83	0.0092	9.05
48	....	12.50	87.50	11.69	88.24	7.543	10,254	.200	1.076	21.42	7,901,458	3,798	3,825	.527	.0053	.99	......	......	24.86	.779	56.50	0.0471	22.93
24	Sn_4Cu	11.84	88.16	11.49	88.47	7.552	10,706	.250	Bent	76.72	10,403,101	6,380	6,627	.549	.0410	.98	10,104	.10+	23.24	.653	61.75	0.0708	23.45
25	Sn_5Cu ...	9.70	90.30	8.57	91.39	7.487	5,305	.250	Bent	43.72	7,965,988	6,450	7,594	.543	.0687	.92	......	.....	22.98	.631	131.75	0.2347	43.85
49	....	7.50	92.50	6.05	93.77	7.417	9,764	.207	Bent	73.79	7,969,719	6,096	8,121	.427	.2022	.87	......	......	19.83	.556	178.00	0.4006	50.66
26	$Sn_{12}Cu$ ...	4.29	95.71	3.72	96.31	7.360	6,925	.190	Bent	39.75	8,613,200	4,780	6,804	.575	.1232	.84	.....	......	22.83	.514	220.50	0.5677	76.28
50	....	2.50	97.50	2.11	97.68	7.342	8,374	.240	Bent	63.64	6,692,585	5,600	12,397	.214	.4000	.68	......	......	15.75	.474	362.00	1.2189	80.15
27	$Sn_{48}Cu$ ...	1.11	98.89	0.74	99.02	7.305	3,964	.333	Bent	33.16	6,771,517	3,650	7,867	......	.2279	.70	......	......	18.20	.448	387.50	1.3388	90.40
28	$Sn_{96}Cu$ ...	0.55	99.43	0.32	99.46	7.299	4,438	.308	Bent	29.94	9,398,659	4,475	13,223	.559	.3544	.58	......	......	16.47	.418	535.30	2.0879	125.99
29	Sn........	0	00	......	......	7.293	3,740	.273	Bent	29.79	6,734,838	3,500	....	.476	.3551	.50	6,400	.10+	12.75	.453	556.75	2.1975	105.45

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* Defective bar.

† Defective transverse bar.

‡ Specific gravity of turnings of ingot-copper, 8.874; specific gravity of turnings of No. 6 A, 8.943.

§ Short bar.

REMARKS UPON THE GENERAL SUMMARY OF RESULTS.

From the results recorded in the above table a number of curves have been plotted (Plates VII to XI), by inspection of which the relations existing between the compositions of the alloys of copper and tin, their density, strength, ductility, and other properties, may be seen more plainly than from the figures. These curves, and the figures from which they were plotted, will now be discussed in order.

VARIATION OF COMPOSITION BY ANALYSIS FROM COMPOSITION BY ORIGINAL MIXTURE, AND LIQUATION OR SEPARATION OF THE METALS.

From the figures given in the tables of analyses and specific gravities (pages 350, 351), under the head of "Variation of composition," a diagram has been plotted to show what relation, if any, this variation of composition bears to the percentages of copper and tin in the original mixture. The diagram does not indicate, however, that this variation follows with certainty any regular law dependent upon the percentage of the metals. In general there appears to be a greater loss of tin than of copper in the bars which contain the greater percentages of copper, and a greater loss of copper than of tin in the bars which contain the larger percentages of tin, and that the bars which contain about equal amounts of the two metals show great tendency to liquation.

In the alloys which contain less than 35 per cent. of tin by original mixture there is a greater loss of tin than of copper, with but three exceptions. In the alloys containing more than 70 per cent. of tin there is a greater loss of copper than of tin, with only one exception. In all of the alloys of these two classes the extreme variation of a single analysis from the original mixture is 3.6 per cent., and generally it is less than one per cent. In the alloys between these limits, or those containing between 35 and 70 per cent. of tin, there are some bars which show great amounts of liquation, and others which show very little. The diagram at this portion of the series is consequently very irregular, and fails to indicate any definite law.

It only seems to show that in these compositions there is a great tendency to liquation, which may or may not take place, according as certain precautions are observed in casting. In the bars whose analyses showed a great amount of liquation it was uniformly the case that the upper part of the bar contained the larger percentage of copper, and from the appearances of the fractures of different portions, the variations in hardness and other properties, as well as some analyses and determinations of density made of different portions of the bar, it appears that there was a regular increase in percentage of copper from the bottom to the top, and that there was no distinct plane of separation between two different but definite compositions. In two cases the differences in composition of the top and bottom of the bar amounted to more than 20 per cent.

In two cases there appeared to be lateral liquation or separation of the metals in such a manner that the exterior of the bar contained a less amount of tin than the interior. The first of these, No. 18 (38.37 copper, 61.32 tin), contained by original mixture 39.20 copper, 60.80 tin. The analyses of the turnings from the tension-pieces, from the top and from the bottom of the bar, the turnings being taken from the whole length of the cylindrical portions of the test-pieces, and including all of the metal in the square portion of the bar except the cylinder in the center, 0.798 inch in diameter, gave almost precisely the same results (43.37 copper, 56.37 tin, and 43.36 copper, 56.40 tin), showing a loss of tin of more than 4 per cent. A piece from the middle of the bar was then analyzed, the whole of the square section being turned into chips. The analysis of this piece gave 38.37 copper, 61.32 tin, or 0.52 per cent. more tin than the original mixture. The other bar, No. 19, showed the same result. The original mixture was 34.95 copper, 65.05 tin, and the analyses of the turnings from the outside of the bar at top and bottom were 40.32 copper, 59.46 tin, and 40.24 copper, 59.44 tin. The analysis of a piece from the middle of the bar gave 34.22 copper, 65.80 tin.

SPECIFIC GRAVITY.

The curve of specific gravities shows a certain degree of regularity, indicating that the densities of these alloys follow a definite law.

The alloys containing less than 25 per cent. of tin show an irregular variation in specific gravity, but this is entirely explained by the fact of the porosity of the metals, and that the determinations were made on large pieces. The figures obtained are, therefore, to be considered as the densities of the *castings*, and not of the metals themselves, as they might be determined in the shape of fine powder, or metal perfectly free from minute cavities.

The densities of the castings are much lower than that of the metal as given by other authorities, and this fact is corroborated by the determinations of the density of No. 6 A (87.15 copper, 12.69 tin) in the shape of fine turnings, which gave the figure 8.943, and of turnings of ingot-copper, which gave the figure 8.874.

It will be noticed that those bars which gave less strength than might be expected from their compositions, and those whose resistances to stress are rejected from the table of averages, also had lower specific gravities than those metals of nearly similar compositions which had greater strength.

From the comparison of the strengths of the bars containing less than 20 per cent. of tin with their densities, it is apparent that the strength and density are in a certain degree dependent upon each other; that is, that the greater the density of an alloy of any given composition containing less than 20 per cent. of tin the greater the strength. This has been plainly shown in experiments by several authorities on gun-metal, which uniformly exhibits an increase of strength with increase of density.

This fact will also account for the much lower strength of the alloy of 90 copper, 10 tin, and of metals of nearly similar composition, than is given by some authorities as the strength of gun-metal. It must be remembered that the casting of small bars, such as have been used in the experiments herein described, is especially unfavorable to the production of metal of great density, while in the casting of guns and other large masses the pressure of molten metal is much greater, and all conditions favor the increase of density.

From a study of the specific gravities of alloys of copper and tin which have been published by other authorities, especially Calvert and Johnson, and Riche, who took especial precautions to obtain the densities of the compacted metals, and comparing them with the figures given above for ingot-copper and No. 6 A in turning, it appears probable that the actual specific gravities of all the alloys containing less than 25 per cent. of tin do not greatly vary from 8.95, and that the specific gravities of castings of these alloys will be less than 8.95 according to their degrees of porosity. Riche gives figures showing the increase of density of several alloys by tempering and compression. The specific gravity of an alloy of 94 copper, 6 tin, was increased from 8.541 to 8.939 by repeated tempering and rolling.

The specific gravity of pure copper, according to a large number of authorities quoted in "*Constants of Nature*," varies from 8.360 to 8.958, electrolytic, hammered, rolled, or pressed copper giving the highest figures and those which probably are the most nearly correct.

The specific gravity of No. 6 A as before stated is 8.943, and those of all the alloys containing between 25 and 38 per cent. of tin, which alloys are all very compact and homogeneous, are greater that 8.9 (reaching 8.97 at the latter percentage), both as determined in these experiments, and as determined by Calvert and Johnson. These results, therefore, tend to confirm the above statement that the specific gravities of all the alloys containing less than 25 per cent. of tin are nearly 8.95, and that a determination which gives a less figure reveals the porosity of the casting.

The specific gravities given in the above tables, as determined from pieces of the castings, are more valuable than if they were determined only from turnings, for the reason that they show the cause of imperfections in strength and other qualities, and indicate that the proper method of improving the strength is to increase the density. They also indicate that the lower the specific gravity of one of these alloys, which shows a certain definite strength, the greater increase may probably be given to that strength by any means which will cause the specific gravity to approach the figure 8.95.

The several methods of increasing the specific gravities of these alloys and thereby increasing their strength yet remain to be experimented upon. It is well known that rolling, hammering, or pressing the porous and ductile metals increases the density. Casting under pressure has the same effect, as shown in the greater density of the bottom of a heavy gun casting than the top or the sinking head, and in a still more marked degree by experiments which have lately been made of casting under very heavy hydraulic pressure. It is probable also that temperature of pouring and rate of cooling have an important influence upon the density, and that the use of any fluxes which may remove occluded gases from the molten metals will be likely to increase it.

The maximum density of the series is given by the alloy No. 12 (62.31 copper, 37.35 tin, by analysis), the original mixture of which corresponds to the formula $SnCu_3$, and it is nearly approached by the alloy No. 38 (62.42 copper, 37.48 tin). The figures are 8.970 and 8.956 respectively. The former is higher than is given by any authority quoted in "*Constants of Nature*" for any alloy of copper and tin. The specific gravity of the same alloy, according to Calvert and Johnson, is 8.954. Calvert and Johnson's maximum figure is 8.965, which was obtained with the alloy, $SnCu_5$ (72.90 copper, 27.10 tin). Bolley states that a large clock bell at Reichenhall, six hundred years old, has a specific gravity of 9.1, its composition being 76.20 copper, 23.80 tin. This figure is so much higher than that given by any other authority that it may be considered doubtful.

From the alloy No. 12 to the end of the series, or to pure tin, there is almost a perfectly regular decrease of specific gravity, that of tin being 7.293, which figure agrees with the results of several other authorities. From the regularity of this decrease of specific gravity, and from the fact that all the results between the alloy containing 62.31 copper, 37.35 tin, and pure tin agree closely with the figures given by other authorities for the specific gravities of the same alloys, as is plainly shown in the curves of comparison of authorities (Plate XII), it appears that these alloys are much less apt to vary in their densities than those containing less than 25 per cent. of tin, and that they have but little, if any, porosity. It is therefore probable that their densities will not greatly vary under different methods of casting and rates of cooling.

It has been observed that the densities of the alloys containing less than 20 per cent. of tin have direct relation to their strengths, the strength being greater as the density is greater. This does not appear to be the case with the alloys containing more tin than the alloy of maximum density, and in these alloys there is a regular decrease of density, but a great irregularity in strength. It has also been noticed that different portions of the same bar vary considerably in strength, but have almost exactly the same density. The variations in strength, as before stated, seem to depend upon the rate of cooling, and possibly upon differences of pressure, causes which apparently have an important influence upon the crystallization, but not upon the density.

COMPARISON OF RESISTANCES.

By inspection of the curves of comparison of strength by transverse, tensile, torsional, and compressive stresses (Plate VII), it will be seen that the curves of tensile and torsional strengths agree very closely, the torsional curves being laid down to such a scale that one foot-pound of torsional moment is equivalent to 200 pounds of tensile strength. The curve of transverse strength is similar to those of tension and torsion (the scale being such that one pound modulus of rupture corresponds to one pound tensile strength), but the ordinates of the points of the curve representing most of the alloys are much greater than in the two latter curves.

The curve of compressive strength is very unlike either of the other curves. Being laid down to the same scale as that of tensile strength the ordinates of the curve are all much higher, showing that the compressive strengths per square inch of all the copper-tin alloys are much greater than their tensile strengths. The maximum compressive strength is reached by one of the brittle alloys, the tensile strength of which was not far from the minimum.

It appears, therefore, that the tensile and compressive strengths of the alloys are in no way related to each other; that the torsional strength is closely proportional to the tensile strength, and that the transverse strength may depend, in some degree, upon the compressive strength, as is indicated by the approach of some portions of the transverse curve to the compression curve, but it is much more nearly related to the tensile strength, as is shown by the general correspondence of the curve of transverse with that of tensile strength. The modulus of rupture, as obtained by the transverse tests, is in general a figure between those of tensile and compressive strengths per square inch, but there are a few exceptions in which it is larger than either.

From the curves of transverse, tensile, and torsional strengths it is seen that the strengths of the alloys at the copper end of the series increase rapidly with the addition of tin, till about 4 per cent. of tin is reached. The transverse strength continues regularly to increase to the maximum, till the alloy containing about 17½ per cent. of tin is reached, while the tensile and torsional strengths also increase, but very irregularly, to this same point. As this irregularity corresponds to the irregularity in the same portion of the curve of specific gravities, it is probably due to porosity of the metal, and might possibly be removed by any means which would make the castings more compact.

The maximum point of the three curves is reached at the same point, viz, at the alloy containing 82.70 copper, 17.34 tin, the transverse strength, however, being very much greater at this point than the tensile or torsional strength.

From the point of maximum strength the three curves drop very rapidly to the alloys containing about 27.5 per cent. of tin, and then more slowly to 37.5 per cent., at which point the minimum or nearly the minimum strength of tin, by all three methods of test, is reached. The compression curve reaches its maximum between these points. The alloys of minimum strength are found from 3.75 per cent. tin to 52.5 per cent. tin; the observations being somewhat irregular between these points, making it difficult to state the exact minimum points of the curve, but all agreeing in showing great weakness. The absolute minimum is probably about 45 per cent. of tin.

From 52.5 per cent. of tin to about 77.5 per cent. tin there is a rather slow and irregular increase in strength to the point which has been called the second maximum, the curve of transverse strength at this point, as at the first maximum, rising much higher than the other two curves. The former, also, does not reach its second maximum at the same point as the two latter, but this may be accidental.

From 77.5 per cent. tin to the end of the series, or all tin, the strengths slowly and somewhat irregularly decrease, the second minimum being reached at the end of the curve. It will be noticed that the irregularity of the torsional curve is much less than those of the other curves, which is probably due to the fact that in the torsional tests the time occupied in making the tests was very uniform, and also that the torsional curve is made from the average results of usually four tests of each bar, while the tensile tests were but two in number from each bar, and the transverse test but one.

One of the most important facts to be learned from the curves is that all the alloys containing more than 25 per cent. tin are practically worthless for all purposes where strength is required, the average strength of these alloys being only about one-sixth of the average of those containing less than 25 per cent. of tin.

COMPARISON OF DUCTILITY.

The ductility of the alloys is shown by the plate (No. IX) of curves of ductility by transverse, tensile, and torsional stresses. These three curves agree in showing that the ductility follows a very regular law, depending upon the composition.

The ductility in the tensile tests was determined by direct observations of the elongations of the pieces under tension. In the cases of the brittle alloys these elongations were such very small quantities that they could not be measured, and the curve, therefore, touches the axis of abscissas.

The ductility in the transverse tests was determined by the final deflections before breaking, and as this was always an appreciable quantity even with the brittle alloys, the curve is easily laid down, except in cases in which the bar bent without breaking. The curve, therefore, cuts the top of the plate in two points, thus indicating that the ductility by transverse stress without those points is indeterminate but very great.

The ductility by torsional tests is determined from the extension of the exterior fiber or line of particles in a torsion-piece one inch long, in parts of an inch, which is calculated from the angle of torsion given by the autographic strain diagram. This gives a correct comparison of the relative ductility of all the pieces tested, whether very brittle or very ductile, and the comparative ductility is given in the figures in the table of summary of results. The maximum angle of torsion given in the summary is 556.75 degrees, which corresponds to an extension of 2.1975 inches of a line of particles, originally one inch long, on a cylinder $\frac{5}{8}$ inch in diameter, on the supposition that the diameter and length of the cylinder while being twisted remained unchanged. The minimum angle of torsion is 0.4 degree, which corresponds to an extension of only 0.000006 inch. The ductility of pure tin being therefore more than 200,000 times that of the most brittle alloy, they cannot both be represented in a curve drawn on the same scale, except when the lower portion of the curve practically coincides with the bottom line of the plate. The curve is therefore drawn so as to make it coincide with the curve of ductility by tensile tests.

Referring to the three curves, it will be seen that the alloys containing less than 12.5 per cent. of tin, and more than 87.5 per cent. of tin, are so ductile that bars of 22 inches in length bend to a deflection of more than 3½ inches without breaking, and their comparative ductility is not, therefore, determined by this method of test. Bar No. 1, all copper, is an exception, but it was considered to be a defective bar. Bar No. 30, all copper, bent without breaking.

The comparative ductility of these alloys is plainly shown by the curves obtained from tensile and torsional tests. From both curves it appears that, beginning at pure copper, the ductility increases slightly with the addition of tin till from 2 to 4 per cent., between which limits the maximum ductility of the stronger alloys is reached. From this point there is a regular curve of decrease of ductility to 25 per cent. tin, at which point it becomes so small that both curves apparently touch the base line. The record of comparative ductility by tension is then entirely lost up to the alloy containing 75 per cent. tin, while that by torsion is lost in the curve, but can be traced from the figures in the table of summary of results. From these figures it is seen that the minimum ductility is reached at from 37.5 to 47.5 per cent. tin, which corresponds nearly to the minimum point of strength.

The curve of ductility by transverse strength, commencing at about 12.5 per cent. tin, shows a regular curvature tending toward the bottom of the plate, to about 35 per cent. tin, and from that point to 55 per cent. tin it is nearly horizontal, indicating a minimum at 45 per cent., thus agreeing with the result obtained from the torsional tests. From 55 per cent. tin there is a very regular curve upward to 87.5 per cent. tin, at which point the transverse curve is lost in consequence of the bars bending without breaking.

The curves of tensile and torsional ductility appear to rise from the bottom line at about 75 per cent. tin, and from that point to the end, or pure tin, there is a very regular increase, the regularity being much greater in the tests by torsion than in those by tension.

TOTAL RESILIENCE.

The resilience or amount of work done in breaking each of the alloys is shown by the figures in the table of summary of results under headings of transverse and torsional tests, and by the curves plotted from these figures.

The work done in breaking any specimen is measured in the same manner as mechanical work of any kind, that is, by the product of a resistance into the distance through which the resistance acts. When the resistance is variable the work is the product of the mean resistance into that distance.

The work done in breaking a piece of metal by tensile stress is equal to the mean resistance multiplied by the total elongation; by transverse stress it is the mean resistance multiplied by the total deflection, and by torsional stress it is the mean resistance of the specimen as measured by the mean ordinate of the autographic strain diagram, expressed in foot-pounds of torsional moment, or pounds acting at the radius of one foot multiplied by the distance through which this moment is exerted as measured by the total abscissa of the diagram and reduced to feet traversed by the resistance.

The resilience under transverse stress has been calculated from the curves of deflections by transverse stress (Plates XVI, XVII). the area of the curve being directly proportional to the resilience, the ordinates representing resistances and the abscissas deflections. The results as given in the tables are reduced to foot-pounds of work. In the cases of the bars which bent to a deflection of more than 3½ inches without breaking, the total resilience within the breaking point could net be determined, and the resilience within the breaking point could not be determined, and the resilience within the limit of 3½ inches deflection has been taken instead.

The torsional resilience has been calculated from the area of the autographic strain diagram in the manner above stated, the total resilience up to the breaking point being taken in each case and reduced to foot-pounds of work.

The resilience under tensile stress has not been determined, since the elongations of all the brittle pieces were not measured, and those of many of the ductile pieces were not determined with the same accuracy which characterized the transverse and torsional tests.

Referring to the plate of curves of resiliences (Plate X) it will be seen that the resilience bears a very close relation to the ductility, the curves of the two properties being nearly similar, except in those portions of the curves representing the ductile alloys, which bent without breaking under transverse stress, and of which the transverse resilience is taken only within a deflection of 3½ inches, while the torsional resilience is taken to the point of rupture.

The maximum torsional resilience is given by bar No. 3 (96.06 copper, 3.76 tin), which was one of the most ductile of the stronger alloys. No. 33 (88.40 copper, 11.59 tin) gave the maximum transverse resilience within the deflection of 3½ inches, on account of its being the strongest alloy which reached that deflection without breaking, but its total resilience is much less than those of the more ductile bars, which bent without breaking to deflections of more than 8 inches.

From the bar which gave the maximum total resilience of 599.96 foot-pounds there is a rapid decrease to No. 8 (76.64 copper, 23.24 tin), which had a resilience of only 3.72 foot-pounds. From No. 8 to No. 20 (35.85 copper, 73.80 tin) all of the bars, with one exception, show total resiliences by torsion of less than one foot-pound each, the minimum being only 0.08 foot-pounds, or only about $\frac{1}{7500}$ part of the maximum. These resiliences being so small compared with the maximum, the curve of resiliences (Plate III) between these points approaches the bottom line of the plate so closely that it apparently coincides with it. The figures for transverse resilience agree quite closely with those of torsional resilience between these points.

From bar No. 20 to No. 28 (0.32 copper, 99.46 tin) there is a gradual increase of the total resiliences to 125.99 foot-pounds, which is the "second maximum" point of the curve. The bar of pure tin shows a somewhat less resilience, on account of its less strength, than No. 28, although it possessed a slightly greater ductility. The second maximum resilience by transverse stress within a deflection of 3½ inches is reached by No. 24 (11.49 copper, 88.47 tin), on account of its having the greatest strength of the bars containing a large amount of tin which bent without breaking. The transverse resiliences (within the deflection of 3½ inches) decrease to No. 29 (all tin), on account of the decrease of strength, while the total resiliences increase on account of the rapid increase of ductility.

LIMIT OF ELASTICITY.

The limit of elasticity has been defined as the point at which the distorsion (either by tension, torsion, compression, or transverse stress) begins to increase in a greater ratio than the force which causes the distortion. It corresponds nearly with the point of first appreciable set, or permanent distortion. In the plotted curves of deflections and elongations and in the autographic diagrams of torsional stress it is the point at which the curve begins (usually suddenly) to change its direction and deflect towards the horizontal.

The plate of curves in which comparison is made of the transverse, torsional, and tensile strengths, also contains curves showing the limit of elasticity under each of the three kinds of tests. These have been plotted from the figures given in the tables of tests by tensile, transverse, and torsional stresses under each series. In the table of general summary of results (Table XIII) the elastic limits are represented for more convenient comparison by parts of the total strengths.

It will be seen that there is a similarity in the curves of limits of elasticity obtained from the three kinds of tests, and that they coincide with the curves of strength in the middle portion or that portion of the series containing the brittle alloys, and fall beneath them at the ends, the figures in the table of summary of results showing the elastic limit to be 100 per cent. of the total strength, and that of the more ductile alloys to be in some cases as small as 20 per cent. of the total strength, and to increase with the decrease of ductility.

There is a considerable difference between the figures representing the ratios of elastic limit to total strength of the ductile alloys as determined by the various methods of tests. In general the ratios obtained by the tensile tests is higher than that obtained by either the transverse or torsional tests, and the two latter more nearly agree.

Referring to the curves and to the figures giving the ratios of elastic limit to breaking load, it is seen that in the stronger alloys, those containing less than 17.5 per cent. of tin, the elastic limit under tensile stress is reached at from 50 to 68 per cent. of the breaking load, and under transverse and torsional stress at about 35 to 45 per cent. As the percentage of tin is increased beyond 17.5 per cent., the ratio of elastic limit to ultimate strength is increased, the alloy No. 8 (76.64 copper, 23.24 tin) giving results which showed the ratio to be 100 per cent., or that the elastic limit was not reached till fracture took place. The same result is given by all the alloys from No. 8 to No. 21 (38.37 copper, 61.32 tin). From No. 21 to pure tin, the elastic limit is reached before fracture, by transverse and torsional tests. In the tensile tests of the alloys containing between 62.5 and 82.5 per cent. of tin the position of the elastic limit is doubtful, but it is probable it was either not reached or only just reached before fracture took place. In these alloys the ratios of elastic limit to ultimate strength appear much higher in tests by torsional than by transverse stress. The ductile alloys containing large percentages of tin give ratios under torsional stress which gradually decrease as the percentage of tin increases, the decrease being nearly regular from 98.5 per cent. to 45.3 per cent. between the alloy of 27.5 copper, 72.5 tin, and pure tin. In the transverse tests the ratio is much more nearly constant, varying somewhat irregularly between the same compositions from 43.8 to 27.3 per cent.

MODULI OF ELASTICITY.

The moduli of elasticity were calculated from the deflections observed in the transverse tests. In the tables of the tests of each bar a large number of moduli of elasticity have been calculated for each test to show the change of this modulus at different parts of the test both within and beyond the elastic limit. In the summary of results by transverse tests, and in the table of general summary of results (Tables II, VIII, and XIII), the figures given are considered to be the most probable modulus of each bar within the elastic limit where the deflections are proportional to the applied loads. The curve (Plate XI) has been plotted from these figures. The figures and the curve show a great irregularity, but not greater than might be expected from metals of different compositions, when it is remembered that the modulus of elasticity of a single metal, wrought iron, has been found by various experiments to vary from 18,000,000 to 40,000,000.

Referring to the figures of moduli in the table of summaries (Table XIII) and to the curve plotted from them, it is seen that in the alloy containing less than 24 per cent. of tin, which includes all the stronger and more valuable alloys of the eleven figures of moduli of elasticity which are considered reliable observations, nine of them are between 13,300,000 and 15,000,000, the other two being 10,203,205, and 12,472,655. These figures sufficiently establish the moduli of elasticity by transverse stress of these alloys to be, as shown by the curve, about 14,000,000.

From 25 per cent. to 35 per cent. tin the modulus seems to be somewhat greater, the four observations next after those above mentioned varying from 14,896,691 to 16,387,041. From 35 to 75 per cent. there is a very great irregularity. This corresponds to the irregularity in strength and other properties as shown by all the tests, but is a much greater irregularity than of any other property. No. 11 (65.34 copper, 34.47 tin) gives a modulus of over 19,000,000, while No. 12 (62.31 copper, 37.35 tin) gives less than half as much. The latter, it will be remembered, was the alloy of greatest density. The two facts may in some way be connected. Bar No. 14 (original mixture, 51.8 copper, 48.2 tin) gives a modulus of only 5,174,546. This bar showed a very great degree of liquation, but its low modulus may be partially due to the fact of the bar being shorter than the standard length of 22 inches between supports. The figure was therefore rejected as unreliable, as were also those of all the short bars. It is remarkable that the other bar which showed very great liquation, No. 17 (original mixture, 41.74 copper, 58.26 tin), should give a modulus of over 23,000,000, the highest figure given by any alloy in either series.

From the alloys containing 70 per cent. tin to pure tin the moduli again become a little more regular, but still varying between 11,520,262 and 6,771,517, the tendency being to decrease as the tin increases. Of the eleven figures of moduli of the alloys containing more than 80 per cent. tin, including the bar of pure tin, nine give moduli between 6,700,000 and 8,000,000, the other two being 8,613,200 and 10,403,101, thus tending to establish the modulus of these alloys at about 7,500,000 to 8,000,000, or a little more than half that of the stronger alloys containing less than 20 per cent. of tin.

EXTRA BARS OF COPPER AND TIN.

During the progress of the experiments which have been described, a number of bars of copper were made in the ingot-mold for the purpose of being broken into small pieces to facilitate the weighing of the mixtures for the alloys. Several of these bars were tested by tranverse, tensile, torsional, and compressive stresses for the purpose of comparing them with the one selected as a standard. The records of all these tests are appended after the records of the tests of the alloys. The following tables give a summary of the results, including those of bars No. 1 and No. 30, which have already been given.

In addition to these, a test was made of an extra bar of Queensland tin, the record of which is also given. The ingot tin from which this bar was cast was furnished to the writer by Hon. Angus Mackay, commissioner from Queensland, Australia, to the Centennial Exhibition at Philadelphia, and was part of the Queensland exhibit. In the summary, its record is compared with that of the Banca tin, bar No. 29.

SUMMARY OF RESULTS OF TESTS OF BARS OF COPPER AND TIN.

TABLE XIV.—TRANSVERSE TESTS.

Number.	Material.	Length between supports.	Breadth b.	Depth d.	Breaking load P.	Modulus of rupture, $R=\frac{3}{2}\frac{Pl}{bd^2}$	Total deflection Δ.	Limit of elasticity. Load.	Limit of elasticity. Parts of breaking load.	Modulus of elasticity.	Remarks.
		Ins.	*Ins.*	*Ins.*	*Lbs.*		*Ins.*				
1	L. S. copper.....	22	0.994	1.010	650	21,251	2.306	225	.346	13,986,605	Broke; very defective.
30	....do...........	22	0.990	0.980	860	29,848	3. +	120	.140	10,203,205	Cast at very high temperature; bent.
53	....do...........	22	1.000	1.000	860	28,380	1.38	350	.407	10,443,980	Cast at high temperature; bent; defective.
54	....do...........	22	1.000	1.000	643	21,219	3.23+	140	.218	11,788,856	Cast at lower temperature than No. 53; bent.
55	....do...........	22	0.985	0.970	860	30,621	3. +	240	.279	10,540,763	Cast at high temperature; bent.
56	....do...........	22	0.972	0.955	640	23,824	3.51+	180	.281	9,339,672	Cast at lower temperature than No. 55; bent.
57	....do...........	22	1.010	1.010	820	26,271	3.77+	200	.244	9,511,283	Bent.
	Mean of 7 bars..	....	......	......	762	25,916	......	....	.274	10,830,623	
58	Queensland tin..	22	1.038	1.323	150	4,559	3. +	40	.267	5,635,593	Bent.
29	Banca tin.......	22	0.993	1.002	110	3,740	3. +	30	.273	6,734,838	Bent.
	Mean of 2 bars..	....	......	......	130	4,150	......	....	.270	6,185,210	

TABLE XV.—TENSILE TESTS.

Number.	Material.	Diameter of sections.		Total elongation—parts of original length.	Tenacity per square inch of—		Elastic limit.		Remarks.
		Original.	Fracture.		Original section.	Fractured section.	Pounds per square inch.	Parts of breaking load.	
		Ins.	*Ins.*		*Pounds.*	*Pounds.*			
1 A	L. S. copper ...	.798	0.790	.0060	14,180	14,464	12,000	......	Very defective.
1 B	.....do..........	.798	0.742	.0033	11,340	11,509	10,000	......	Do.
Mean	....	.798	0.766	.0047	12,760	12,987	11,000	.862	
30 A	L. S. copper	.798	0.725	.0752	29,200	34,790	14,000	......	
30 B	.....do..........	.798	0.740	.0541	26,400	30,201	14,000	......	
Mean	....	.789	0.733	.0647	27,800	32,496	14,000	.518	
51 A	L. S. copper	.798	0.775	.0261	14,540	15,412	9,840	......	Fluxed with fluor-spar.
51 B	.....do..........	.798	0.763	.0743	20,440	22,353	10,000	......	Do.
Mean	....	.798	0.769	.0502	17,490	18,883	9,920	.567	
52 A	L. S. copper	.798	0.775	.0160	16,940	17,956	9,800	.....	
52 B	.....do..........	.798	0.711	.0916	21,600	27,204	11,200	......	
Mean	....	.798	0.743	.0538	19,270	22,580	10,500	.465	
53 A	L. S. copper .. .	.798	0.780	.0163	18,800	19,763	12,800	.681	Very defective.
53 B	.....do..........	.798	....	....	9,200	....	....	......	Do.
Mean	....	.798	....	....	14,000	....	....	......	
57 A	L. S. copper	.798	0.738	.0934	26,000	30,308	11,000	......	
57 B	.....do..........	.798	0.724	.0717	29,820	36,217	12,000	......	
Mean	....	.798	0.731	.0826	27,910	33,308	11,500	.412	
	Mean of all.....	......	....	.0454	19,872	23,336	11,620	.584	
58 A	Queensland tin.	.798	0.580	....	2,000	....	... ...	......	Slow test.
58 B	.....do..........	.798	0.542	....	3,520	....	....	......	Rapid test.
Mean	....	.798	0.561	......	2,760	....	....	......	
29 A	Banca tin	.798	0.490	.2833	2,800	....	....	......	Slow test.
29 B	.....do.........	.798	0.300	.4269	4,200	....	2,000	.476	Rapid test.
Mean	....	.798	0.395	.3551	3,500	....	. ....	......	
	Mean of all	......	....	.3551	3,130	....	....	......	

TABLE XVI.—TORSIONAL TESTS.

Averages of the Results calculated from the Autographic Strain Diagrams.

Number.	Material.	Area of diagram.	Angle of torsion.	Ordinates of diagram.		Torsional moment.		Extension of exterior fiber.	Resilience.	No. of pieces averaged.	Remarks.
				Maximum.	At elastic limit.	Maximum.	At elastic limit.				
		Sq. ins.	*Degrees*	*Ins.*	*Ins.*	*Ft. lbs.*	*Ft. lbs.*		*Ft. lbs.*		
1	L. S. copper.....	1.30	40.5	0.47	0.19	65.66	33.17	0.0255	37.71	3	Defective.
30	.....do	17.61	153.0	1.38	0.46	143.24	50.63	0.3084	320.35	4	
51	.....do	10.99	136.1	1.05	0.36	109.27	42.81	0.2486	201.95	4	
52	.....do	12.51	154.7	1.07	0.28	119.97	34.44	0.3159	285.75	3	
53	.....do	3.92	52.0	0.90	0.38	94.73	41.80	0.0434	90.29	4	Defective.
57	.....do	9.23	111.2	0.95	0.35	99.77	39.28	0.1790	170.12	4	
	Mean of all	9.26	107.9	1.09	0.34	105.44	40.35	0.1868	184.36	....	
58	Queensland tin..	42.78	691.0	0.73	0.22	13.15	4.36	2.9029	208.48	3	
29	Banca tin.......	21.26	556.8	0.48	0.13	12.75	5.78	2.1975	105.45	4	
	Mean	32.02	623.9	0.61	0.18	12.95	5.07	2.5502	156.97	....	

TABLE XVII.—AVERAGE RESULTS OF TESTS OF COPPER, REJECTING THOSE MARKED DEFECTIVE, AND AVERAGE OF ALL TESTS OF TIN.

	Transverse tests.				Tensile tests.				Torsional tests.				
						Tenacity per square inch of—							
	Breaking load.	Modulus of rupture.	Elastic limit—parts of breaking load.	Modulus of elasticity.	Elongation—parts of original length.	Original section.	Fractured section.	Elastic limit—parts of breaking load.	Maximum torsional moment.	Torsional moment at elastic limit.	Elastic limit—parts of breaking load.	Extension of exterior fiber.	Resilience.
Copper......	765	26, 357	. 232	10, 076, 756	. 0628	23, 118	26, 817	. 491	118. 06	41. 79	. 354	0. 2630	244. 54
Tin.........	130	4, 150	. 270	6, 185, 210	. 3551	3, 130	....	. 476	12. 95	5. 07	. 392	2. 5502	156. 97

TABLE XVIII.—ANALYSES OF TURNINGS FROM FOUR BARS OF COPPER.

	No. 1.	No. 30.	No. 53.	No. 57.
Metallic silver	0. 035	0. 014	0. 015	0. 063
Metallic iron	0. 020	0. 014	0. 035	0. 014
Metallic zinc	0. 014	0. 057	0. 016	None.
Metallic lead	Trace.....	Trace.....	None	Trace.
Metallic bismuth	None	None	None	None.
Metallic arsenic	None	None	None	None.
Metallic antimony	None	None . ..	None	None.
Suboxide of copper	12. 086	3. 580	6. 730	1. 620
Metallic copper	87. 900	96. 330	93. 200	98. 330
Insoluble matter	. .....	....	....	0. 005
Carbon	None . .	....	....	....
	100. 055	99. 995	99. 996	100. 032

TABLE XIX.—ANALYSIS OF "QUEENSLAND TIN."

	Per cent.		Per cent.
Lead	0. 165	Antimony	none.
Iron	0. 035	Bismuth	"
Manganese	0. 006	Nickel	"
Arsenic	trace.	Cobalt	"
Copper	none.	Tungsten	"
Zinc	"	Molybdenum	"

It will be observed that there is a very considerable difference both in strength and ductility of the several bars which were cast from the same metal, and under nearly the same conditions. The causes of this difference have not been ascertained, as the bars were merely cast incidentally during the mixing of the alloys, and no attempt was made to learn exactly the conditions under which each casting was made. A special investigation would be needed before it could be definitely asserted what was the cause of the good or the bad qualities of any particular bar, or how the defects of any of them might be remedied.

The analysis of bars No. 1, No. 30, No. 53, and No. 57 show that the brittleness is an accompaniment of a large percentage of suboxide of copper in the bar, the presence of which is probably the proximate cause of the brittleness. The analysis of No. 1 showed it to contain 12.086 per cent. suboxide of copper; No. 30, 3.580 per cent.; No. 53, 6.730 per cent.; and No. 57, 1.620 per cent.

No. 1 and No. 53 broke under transverse stress, the former with a deflection of 2.306 inches, the latter with 1.38 inches. All the others bent without breaking. No. 1 was recast several times, which might have been the cause of its being defective, but No. 53 was nearly as defective, while it was cast only once. No. 53 and No. 54 were cast at the same time, the former being at the higher temperature, as judged by the founder from its appearance when poured. No. 55 and No. 56 were cast subsequently, and their relative temperatures were determined in the manner described in treating of the casting of the second series of the alloys, viz, by pouring a portion of the molten metal into water and noting the rise of temperature of a given weight of water and the weight of metal poured. The following are the data of these temperature tests:

No.	Weight of water.	Weight of metal.	Temperature of water.			Assumed specific heat.	Calculated relative temperature.	
			Initial.	Final.	Increase.		Fahrenheit.	Centigrade
	Grammes.	*Grammes.*	*Deg. Fahr.*	*Deg. Fahr.*	*Deg. Fahr.*		*Degrees.*	*Degrees.*
55	5445.6	579.6	46	79	33	0.09515	4145.93	1828.26
56	5445.6	325.6	51½	73½	22	0.09515	4927.01	2175.56

No. 56 was supposed to have been cast at least as hot as No. 53, but the test showed the former to be a very good bar, while the latter was a very bad one. The difference in temperatures of casting, therefore, does not seem sufficient to explain the difference in properties of the casting.

No. 30 was cast at an extremely high temperature, much higher than either of the other bars, being of a dazzling white heat. On pouring a small portion into water in attempting to obtain the relative temperature, a severe explosion took place, and this was repeated every time that even a small drop of the molten metal touched the water. The cold ingot mold was then filled with this very hot metal. After the metal remaining in the crucible had stood for several minutes and had cooled considerably, it could be poured into water without causing the slightest explosion.

It might be supposed that the result of this casting at a very high temperature would be to make bar No. 30 a bad bar, as this seems to be indicated by bars No. 53 and No. 54, and also by the experiments of Major Wade on gun-metal. The result, however, showed the contrary, as it proved to be equal to any of the bars which were cast.

No. 57 was cast apparently at a medium temperature, much lower than No. 30, but it is not known how its temperature compared with that of others. The test showed it to be nearly as good a bar as No. 30.

The tensile and torsional tests indicate the qualities of the different bars even more plainly than the transverse tests. The tables explain themselves sufficiently.

It will be observed that the tensile tests show a much greater difference between the bars than do the transverse. The reason of this is, no doubt, that the tensile test-piece always breaks at its weakest section, no one part of the cylindrical portion of the piece being subjected to a greater stress than the others, while in the transverse test the middle section is the dangerous section, or position of maximum strain, and the bar will usually break in the middle, although other portions may be weaker. In defective bars, therefore, the tensile test usually reveals the defects more plainly than the transverse test, especially if these defects are unevenly distributed.

The cause and method of prevention of the defects in cast copper yet remain to be investigated.

The bar of Queensland tin proved to be a very good bar, showing a somewhat greater strength by transverse and torsional tests than the bar of Banca tin, but a less strength by tension. The transverse strength is probably higher both on account of the different methods of test, the bar of Banca tin being tested by dead loads and that of Queensland tin by the platform-scale apparatus, and on account of a flaw in the middle of the Banca-tin bar.

The effect of slow and rapid test is shown by both bars in the tensile test. The average tenacity of all the pieces tested is given as 3,130 pounds per square inch, but it is probable that all the pieces would have broken at as low as 2,000 pounds if the test had been of long duration, say one hour, or as high as 4,000 pounds if each test had been made in, say, five minutes.

The effect of time is also shown in the autographic strain diagrams and in the records calculated from them.

The Queensland tin showed an extraordinary ductility in the torsional tests, one of the pieces twisting through an angle of 818 degrees, or more than 2¼ turns before breaking. This represents an elongation of a line of particles parallel to the axis on the surface of the cylindrical portion of the test-piece from one inch to 4.57 inches.

COMPARISON OF AUTHORITIES.

The following table gives a list of about 140 different alloys of copper and tin, including all those which have been described in this report, together with a large number collated from standard authorities, giving some of their mechanical and physical properties. The results obtained by experimenters, whose investigations were sufficiently complete to allow of such a comparison, are shown graphically in Plates XII, XIII, XIV, XV.

LIST OF AUTHORITIES.

Abbreviations.

B.—Bolley. *Essais et Recherches Chimiques*, Paris, 1869, pp. 345, 348.
Cr.—Croockewit. *Erdmann's Journal*, 1848, vol. 45, pp. 87–93.
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TABLE XX.—PROPERTIES OF THE ALLOYS OF COPPER AND TIN.

COMPARISON OF SEVERAL AUTHORITIES.

Number.	Atomic formula.	Composition of original mixture.		Composition by analysis.		Specific gravity.	Color.	Fracture.	Tenacity, pounds per square inch.	Order of ductility (Mallet).	Relative ductility (Thurston).	Hardness (Mallet, and Calvert and Johnson).	Order of malleability (Mallet).	Order of fusibility (Mallet).	Conductivity for heat, silver=100.	Conductivity for electricity, silver=100.	Authority.	Remarks.
		Cu.	Sn.	Cu.	Sn.													
1		100	0			8.791*a* 8.874*b*	Copper red	Fibrous	27,800		30.8						U. S. B.	*a* Specific gravity of bar. *b* Specific gravity of turnings from ingot.
2		100.00	0.00			8.667	Tile red	Earthy	55,104	1		10	2	16			M.	
3		100.00	0.00			8.921										93.16	Ma.	
4		100.00	0.00									301			81.1		C. J.	
5		100.00	0.00			8.794											Cr.	
6		100.00	0.00			8.921											Mar.	Cast copper.
7		100.00	0.00			8.952											Mar.	Sheet copper.
8		100.00	0.00												73.6	79.3	We.	
9		100.00	0.00			8.672			24,252								Na.	Mean of 9 samples.
10		98.59	1.41													62.46	Ma.	
11	Sn Cu_{96}	98.10	1.90	97.89	1.90	8.564	Red	Vesicular			100.1						U. S. B.	Defective bar.
12		98.04	1.96														B.	Can be forged like copper.
13		98.00	2.00														La.	Ramrods for guns.
14		97.50	2.50			8.511	Red	Vesicular									U. S. B.	Defective bar.
15		96.97	3.03														W.	Resists action of hydrochloric acid.
16	Sn Cu_{48}	96.27	3.73	96.06	3.76	8.649	Reddish yellow	Vesicular	32,000		70.3						U. S. B.	
17		96.00	4.00			8.947											Ri.	Annealed and compressed.
18		95.00	5.00				Golden yellow										W.	Hard malleable.
19		94.10	5.90														B.	Pieces of machines.
20		94.00	6.00			8.939											Ri.	Specific gravity after repeated tempering.
21		93.98	6.02													19.68	Ma.	
22	Sn Cu_{25}	93.17	6.83			8.820						602.08					C. J.	
23	Sn Cu_{24}	92.80	7.20			8.694	Reddish yellow	Vesicular	28,540		21.9						U. S. B.	
24		92.50	7.50			8.684	do	do	27,900		43.2						U. S. B.	
25		92.00	8.00														B.	Bronze for medals.
26		91.75	8.25														W.	Shows separation of metals when examined with a lens.
27		91.74	8.26														B.	English ordnance.
28		91.70	8.30														B.	Ordnance-metal.
29		91.66	8.33														B.	8-pounder guns.

30	$SnCu_{20}$	91.49	8.51			8.793						639.58					C. J.	
31		91.30	8.70														B.	Toothed wheels.
32		90.91	9.09						32,093								Mus.	Prussian ordnance.
33		90.90	9.10														B.	Ordnance-metal.
34		90.73	9.27														B.	French ordnance.
35		90.10	9.90														B.	
36		90.00	10.00	90.27	9.58	8.669	Grayish yellow	Earthy	26,860		18.0						U. S. B.	Compressed ordnance-bronze.
37		90.00	10.00			8.875											De.	
38		90.00	10.00			8.935											Ri.	After repeated compression.
39		90.00	10.00														B.	Railroad-car bearings.
40		89.30	10.70														B.	Ordnance-metal.
41		89.29	10.71			8.953			37,688								Wa.	Small bar cast in iron mold.
42		89.29	10.71			8.318			25,788								Wa.	Small bar cast in clay mold.
43		89.29	10.71			8.358			26,011								Wa.	Mean of 12 gun-heads.
44		89.23	10.77														B.	Ordnance-metal.
45	$SnCu_{15}$	89.00	11.00			8.84											Ri.	
46	$SnCu_{15}$	88.97	11.03			8.825						772.92					C. J.	Mean of 83 gun-heads.
47		88.89	11.11			8.523			29,655								Wa.	
48		88.39	11.61													12.10	Ma.	Gun-metal.
49		88.00	12.00														La.	
50		87.65	12.35													10.15	Ma.	
51		87.50	12.50			8.648	Grayish yellow	Earthy	31,100		7.3						U. S. B.	Regulator Belgian locomotive.
52		86.80	12.40														W.	
53	$SnCu_{12}$	86.57	13.43	87.15	12.73	8.681*a* 8.943*b*	Mottled white and yellow.	Fine vesic.	29,430		13.9						U. S. B.	*a* Specific gravity of bar. *b* Specific gravity of fine turnings.
54		86.21	13.79			8.87											W.	Densest of all alloys? (Riche.)
55		86.00	14.00														W.	Axle-tree bed. Seraing locomotive.
56		85.71	14.29						44,071								Mus.	
57		85.09	14.91													8.82	Ma.	
58	$SnCu_{10}$	84.33	15.67			8.87											Ri.	
59		84.39	15.68			8.832						916.66					C. J.	
60		84.29	15.71			8.561	Reddish yellow, 1.	Fine cryst.	36,064	2		8	6	15			Ml.	
61		84.00	16.00														B.	Carriage-wheel boxes.
62		83.30	16.70														B.	Jeweler's punches.
63	$SnCu_{9}$	82.81	17.19			8.462	Reddish yellow, 2.	Fine cryst.	34,048	3		5	7	14			Ml.	
64		82.50	17.50			8.792	Reddish gray	Fine cryst.	36,200		0.82						U. S. B.	Strongest of series.
65		82.00	18.00			8.927											R.	Annealed and tempered.
66	$SnCu_{8}$	81.15	18.85			8.86											Ri.	
67	$SnCu_{8}$	81.10	18.90			8.459	Yellowish red, 2.	Fine cryst.	39,648	4		4	10	13			Ml.	
68				80.43	19.57	8.953											Th.	Chinese gong.

TABLE XX.—PROPERTIES OF THE ALLOYS OF COPPER AND TIN

COMPARISON OF SEVERAL AUTHORITIES—Continued.

Number.	Atomic formula.	Composition of original mixture.		Composition by analysis.		Specific gravity.	Color.	Fracture.	Tenacity, pounds per square inch.	Order of ductility (Mallet).	Relative ductility (Thurston).	Hardness (Mallet, and Calvert and Johnson).	Order of malleability (Mallet).	Order of fusibility (Mallet).	Conductivity for heat, silver=100.	Conductivity for electricity, silver=100.	Authority.	Remarks.
		Cu.	Sn.	Cu.	Sn.													
69		80.00	20.00			8.7											B.	Bells of Reichenhall, 300 years old.
70		80.00	20.00						35,739								Mus.	
71		80.00	20.00			8.850											Ri.	Annealed and tempered.
72		80.00	20.00			8.955											Ri.	After repeated compression.
73		80.00	20.00	80.95	18.84	8.740	Reddish gray	Fine gran	32,980		0.40						U. S. B.	
74		79.20	20.80			8.927											Ri.	Annealed and tempered.
75	Sn Cu$_7$	79.02	20.98			8.90											Ri.	
76	Sn Cu$_7$	78.97	21.03			8.728	Yellowish red, 1.	Vitr. conch	30,464	5		3	11	12			Ml.	
77		78.00	22.00														B.	Best bell-metal.
78		77.50	22.50			8.917	Pinkish gray	Fine gran	24,650		0.03						U. S. B.	
79	Sn Cu$_6$	76.32	23.68	76.64	23.24	8.565		Smooth	22,010		0.02						U. S. B.	
80	Sn Cu$_6$	76.31	23.69			8.91											Ri.	
81	Sn Cu$_6$	76.29	23.71			8.750	Bluish red	Vitreous	21,728	0		2	12	11			Ml.	
82		76.20	23.80			9.1(?)											B.	Church bell in Reichenhall, 600 years old.
83		75.20	24.80														B.	Swiss clock bells, brittle.
84		75.00	25.00			8.879	Reddish white										W.	
85	Sn Cu$_5$	72.91	27.09			8.87											Ri.	
86	Sn Cu$_5$	72.90	27.10			8.965						Broke.			20.7		C. J.	
87	Sn Cu$_5$	72.80	27.20			8.575	Bluish red	Conchoidal	10,976	0		1	13	10			Ml.	
88		72.50	27.50			8.925	Reddish white	Conchoidal	6,493		0.008						U. S. B.	
89		70.00	30.00	69.84	29.89	8.982	White	Conchoidal	5,585		0.008						U. S. B.	
90		68.82	31.18														B.	Mirror of telescope.
91	Sn Cu$_4$	68.28	31.72			8.80											Ri.	
92	Sn Cu$_4$	68.27	31.73			8.948						Broke.			15.5		C. J.	
93	Sn Cu$_4$	68.25	31.75	68.58	31.26	8.938	White	Conchoidal	1,620								U. S. B.	
94	Sn Cu$_4$	68.21	31.79			8.400	Ash gray	Conchoidal	1,568	0		6	14	9			Ml.	
95		68.21	31.70														B.	Mirror metal.
96		67.50	32.50			8.907	White	Conchoidal	2,586		0.009						U. S. B.	
97		66.67	33.33				Steel gray										W.	Hard, uniform.
98		66.67	33.33						1,017								Mus.	
99		65.00	35.00	65.34	34.47	8.947	Bluish gray		2,201		0.002						U. S. B.	

100		62.50	37.50			8.956	Dark gray	Radiated cryst.	1,561		0.001						U. S. B.	
101	$SnCu_3$	61.79	38.21			8.954						Broke			49.4		C. J.	
102	$SnCu_3$	61.79	38.21			8.96											Ri.	
103	$SnCu_3$	61.71	38.29			8.970	Dark gray	Rough, stony.	688		0.003						U. S. B.	Greatest density, weakest.
104	$SnCu_3$	61.69	38.31			8.539	Dark gray	Tabular cryst.	1,120	0		7	16	8			Ml.	
105		60.00	40.00														B.	White bell-metal.
106		57.50	42.50			8.781	Light gray	Stony	1,877		0.001						U. S. B.	
107	Sn_5Cu_{12}	56.32	43.68	56.70	43.17	8.682	do	do	1,455		0.003						U. S. B.	
108		52.50	47.50			8.643	do	do			0.001						U. S. B.	Weakest under transverse stress.
109	$SnCu_2$	51.84	48.16			8.57											Ri.	
110	$SnCu_2$					8.512											Cr.	
111	$SnCu_2$	51.83	48.17			8.533						Broke			42.8		C. J.	
112	$SnCu_2$	51.80	48.20	51.62	48.09	8.560	Light gray		2,555		0.003						U. S. B.	Remarkable for liquation.
113	$SnCu_2$	51.75	48.25			8.416	Grayish white	Vit. conch.	3,808	0		9	15	7			Ml.	
114		50.00	50.00						725								Mus.	
115		50.00	50.00			8.79	Bluish white										W.	Very slightly malleable.
116	Sn_7Cu_{12}	47.95	52.05	47.61	52.14	8.442	Grayish white	Fine grain	1,525		0.003						U. S. B.	
117		47.50	52.50			8.446	do	Crystal	2,407		0.003						U. S. B.	
118	Sn_2Cu_3	44.67	55.33			8.30											Ri.	
119	Sn_2Cu_3	44.63	55.37	44.52	55.28	8.312	Grayish white	Crystal	3,010		0.003						U. S. B.	
120		42.50	57.50			8.437	do	do	2,098		0.006						U. S. B.	
121	Sn_3Cu_4	41.74	58.26	42.38	57.30	8.302	do	do	3,910		0.007						U. S. B.	
122		40.00	60.00														B.	White bell-metal.
123	Sn_5Cu_6	39.20	60.80	38.37	61.32	8.182	Grayish white	Crystal	2,820		0.005						U. S. B.	
124		37.50	62.50			8.101	do	do	2,400		0.004						U. S. B.	
125	$SnCu$	34.99	65.01			8.12											Ri.	
126	$SnCu$	34.98	65.02			7.992						Broke			41.5		C. J.	
127	$SnCu$					8.072											Cr.	
128	$SnCu$	34.95	65.05	34.22	65.80	8.018	Grayish white	Crystal	3,371		0.005						U. S. B.	
129	$SnCu$	34.92	65.08			8.056	do	Tab. cryst.	3,136	0		11	9	6			Ml.	
130		33.33	66.67				White										W.	Brittle; uniform.
131		32.50	67.50			7.931	Grayish white	Crystal	2,822		0.014						U. S. B.	
132	Sn_4Cu_3	28.72	71.28	25.85	73.80	7.948	do	do	1,648		0.011						T.	
133		27.50	72.50			7.915	do	do	4,380		0.018						T.	
134		25.00	75.00			7.813	Bluish white	do									W.	
135	Sn_5Cu_3	24.88	75.62	23.35	76.29	7.835	Grayish white	Fine cryst.	6,775		0.08						T.	
136		22.50	77.50			7.774	do	do	5,000		0.12						T.	
137		21.74	78.26	21.38	77.63	7.53	Whitish										W.	Yellow, greenish white, shining.
138	Sn_2Cu	21.21	78.79			7.738						135.42			43.1		C. J.	
139	Sn_2Cu	21.21	78.79			7.74											Ri.	
140	Sn_2Cu	21.18	78.82	20.25	79.63	7.770	Grayish white	Crystal	4,337		0.06						T.	
141	Sn_2Cu	21.15	78.85			7.387	do	Coarse crystal.	3,736	0		12	8	5			Ml.	
142	Sn_5Cu_2	17.68	82.32			7.652											Cr.	
143		17.50	82.50			7.690	Grayish white	Crystal	2,816		0.20						T.	
144		16.40	83.60													12.76	Ma.	
145	Sn_3Cu	15.21	84.79			7.53											Ri.	

TABLE XX:—PROPERTIES OF THE ALLOYS OF COPPER AND TIN.

COMPARISON OF SEVERAL AUTHORITIES—Continued.

Number.	Atomic formula.	Composition of original mixture.		Composition by analysis.		Specific gravity.	Color.	Fracture.	Tenacity, pounds per square inch.	Order of ductility (Mallet).	Relative ductility (Thurston).	Hardness (Mallet, and Calvert and Johnson).	Order of malleability (Mallet).	Order of fusibility (Mallet).	Conductivity for heat, silver=100.	Conductivity for electricity, silver=100.	Authority.	Remarks.
		Cu.	Sn.	Cu.	Sn.													
146	Sn_3Cu	15.21	84.79			7.606						104.17			42.3		C. J.	
147	Sn_3Cu	15.19	84.81	15.08	84.62	7.657	Grayish white.	Crystal	6,520		0.92						T.	
148	Sn_3Cu	15.17	84.83			7.447	do	Coarse crystal.	6,944	0		13	15	4			Ml.	
149		12.50	87.50			7.543	do	Crystal	3,798		4.71						T.	
150	Sn_4Cu	11.86	88.14			7.558						95.81			40.6		C. J.	
151	Sn_4Cu	11.84	88.16	11.49	88.47	7.532	Grayish white.	Crystal	6,380		7.08						T.	
152	Sn_4Cu	11.84	88.16			7.50											Ri.	
153	Sn_4Cu	11.82	88.18			7.472	Grayish white.	Coarse crystal.	6,944	8		14	4	3			Ml.	
154	Sn_5Cu	9.73	90.27			7.517						83.33			39.6		C. J.	
155	Sn_5Cu	9.73	90.27			7.52											Ri.	
156	Sn_5Cu	9.70	90.30	8.57	91.89	7.487	Grayish white.	Granular	6,450		23.47						T.	
157	Sn_5Cu	9.68	90.32			7.442	do	Earthy	3,360	6		15	3	2			Ml.	
158		9.09	90.91			7.472											W.	Slightly malleable.
159		7.50	92.50			7.417	Grayish white.	Granular	6,096		40.06						U. S. B.	
160		6.43	93.57													12.03	Ma.	
161	$Sn_{12}Cu$	4.29	95.71	3.72	96.31	7.360	Grayish white.	Granular	4,780		56.77						U. S. B.	
162		2.50	97.50			7.342	do	Fibrous	5,600		121.9						U. S. B.	
163	$Sn_{48}Cu$	1.11	98.89	0.74	99.02	7.305	do	do	3,650		133.9						U. S. B.	
164	$Sn_{96}Cu$	0.56	99.44	0.32	99.46	7.299	do	do	4,475		208.8						U. S. B.	
165	Sn	0	100			7.293	do	do	3,500		219.8						U. S. B.	
166		0	100			7.291	White	do	6,040	7		16	1	1			Ml.	
167		0	100			7.297			2,122								Wa.	
168		0	100			7.294										11.45	Ma.	
169		0	100			7.305											Cr.	
170		0	100									27			42.2		C. J.	
171		0	100												15.2	17.0	We.	

In the above table the figures of order of ductility, malleability, hardness, and fusibility (see also Plate XV) are taken from Mallet's experiments on a series of 16 alloys,* the figure 1 representing the maximum and 16 the minimum of the property. The ductility of the brittle metals is represented by Mallet as 0.

The relative ductility given in the table, of the alloys experimented on by the board, is the proportionate extension of the exterior fibers of the pieces tested by torsion as determined by the autographic strain-diagrams. It will be seen that the order of ductility differs widely from that given by Mallet.

The figures of relative hardness, on the authority of Calvert and Johnson (Plate XV), are those obtained by them by means of an indenting tool. The figures are on a scale in which cast iron is rated at 1,000. The word "broke" in this column indicates the fact that the alloy opposite which it occurs broke under the indenting tool, showing that the relative hardness could not be measured, but was considerably greater than that of cast iron.

The figures of specific gravity show a fair agreement among the several authorities in the alloys containing more than 35 per cent. of tin, except those given by Mallet, which are in general very much lower than those by all the other authorities. In the alloys containing less than 35 per cent. of tin there is a wide variation among all the different authorities, Mallet's figures, however, being generally lower than the others. Several of the figures of specific gravity have been selected from Riche's results of experiments on the effects of annealing, tempering, and compression, which shows that the latter especially tends to increase the specific gravity of all the alloys containing less than 20 per cent. tin to about 8.95. This result, as stated in the discussion on specific gravity (page 355), is due merely to the closing up of the blowholes, and thus diminishing the porosity. The specific gravity of 8.953 was obtained by Major Wade by casting a small bar in a cold iron mold from the same metal which gave a specific gravity of only 8.313 when cast in the form of a small bar in a clay mold. The former result is exceptionally high, and indicates, the probability that every circumstance of the melting, pouring, casting, and cooling was favorable to the exclusion of the gas which forms blowholes, and to the formation of a perfectly compact metal.

Plate XII gives a comparison of the figures of specific gravity obtained by different experimenters.

The figures of tenacity given by Mallet, Muschenbroek, and Wade agree with those found in the experiments described in this report as closely as could be expected from the very variable strengths of alloys of the same composition which have been found by all experimenters.

Mallet's figure for copper, 24.6 tons or 55,104 pounds, is certainly much too high for cast copper; the piece which he tested was probably rolled or perhaps drawn into wire. Haswell's Pocket Book gives the following as the tensile strength of copper; the names of the authorities are not given:

	Pounds per square inch.
Copper, wrought	34,000
Copper rolled	36,000
Copper, cast (American)	24,250
Copper, wire	61,200
Copper, bolt	36,800

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* See appendix.

The figure for cast American copper is evidently taken from the experiments of Major Wade.

The figures obtained by the writer for alloys of 7.5, 10, and 12.5 per cent. tin, viz, 27,900, 26,860, and 31,100 pounds, are much less than is usually given as the strength of gun-metal. It must be remembered, however, that bronze guns are usually cast under the pressure of a head of metal which tends to increase the strength and density. The strength of the upper part of a gun-casting, or sinking head, is not greater than those of the small bars which have been tested in these experiments. The table shows the figures of Major Wade for the mean density and tenacity of a lot of 83 gun-heads of one composition, and of 12 of another composition, the figures for tenacity being respectively 26,655 and 26,011 pounds per square inch.

The strength of gun-bronze, as found in the guns, is not given in the table, which is designed to compare only the various authorities on the tenacities of the alloys only, as cast under ordinary conditions, and not when compressed, rolled, or cast under pressure.

The following are a few extracts which have been made from the report of Major Wade concerning the strength and density of gun-bronze:

Bronze guns made at Chicopee, Mass., 1850.

	Specific gravity.	Tenacity.
Tin, 1 part	7.297	2,122
Copper, 8 parts (mean of 9 samples)	8.672	24,252
Mean of 83 guns	8.751	......
Mean of 83 gun-heads	8.523	29,655

Extreme variation of six samples from different parts of the same gun (a 32-pounder howitzer): Specific gravity, 8.487 to 8.835; tenacity, 26,428 to 52,192. Extreme variation of all the samples tested: Specific gravity, 8.308 to 8.850; tenacity, 23,108 to 54,531. Extreme variation of all the samples from the gun-heads: Specific gravity, 8.308 to 8.756; tenacity, 23,529 to 35,484.

The materials used in all these castings were of the same quality; they were melted, cast, and cooled in the same manner, and were designed to be similarly treated in all respects.

Bronze guns made at South Boston, Mass., 1850—*12-pounder howitzers. Composition*, 10.71 *parts tin in* 100.

	Specific gravity.	Tenacity.
Mean of 12 gun-heads	8.353	26,011
Mean of 12 small bars cast with gun	8.800	52,253

The small bars were cast in the same mold as the gun and were subjected to the pressure of the sinking head. Major Wade remarks that the great superiority of the small bars over the gun-heads may be attributed to their cooling rapidly at first, and until they become solid, and to their subsequent cooling being retarded by the adjacent liquid mass of metal in the gun-head. The bar is in contact at one end with the gun-head, and any contraction which may occur in it after its solidification is supplied by the liquid metal in the head, with a force due to its column of pressure. This fills all cavities and gives compactness to the bar. The heat in the massive head which joins the bar controls and prolongs its cooling. Small bars, cast in separate molds, are cooled

rapidly from first to last, and the cavities formed during their contraction are not supplied from any separate source. To these circumstances we must attribute their inferiority to the bars cast in the gun-molds.

Three howitzers, Nos. 27, 28, and 29, were cast from the same liquid metal contained in a crane-ladle. No. 27 was cast when the metal was at the highest temperature; No. 28 was cast fifteen minutes later; and No. 29 fourteen minutes after No. 28. The following results were obtained:

Number.	Time of metal in ladle, minutes.	Temperature of metal at casting.	Specific gravity—				Tenacity.		
			Of gun-heads.	Of entire gun.	Of small bars cast in—		Of gun-heads.	Of small bars cast in—	
					Gun-mold.	Separate mold.		Gun-mold.	Separate mold.
27	0	Highest..........	7.986	8.195	8.686	8.554	17,761	50,973	31,132
28	15	Mean............	8.351	8.551	8.823	8.447	28,995	52,330	28,153
29	29	Lowest..........	8.538	8.752	8.846	8.376	23,722	56,786	28,082

In casting another howitzer, No. 30, small test-bars were cast in separate molds, one of which was of cast iron, to ascertain the effect of sudden cooling, and the others were of clay, similar to the gun-mold. The tests of all the samples from this casting were as follows:

	Specific gravity.	Tenacity.
Small bars cast separately in iron mold	8.953	37,688
Small bars cast separately in clay mold	8.313	25,783
Small bars cast in gun-mold..	8.896	53,798
Gun-head samples..	8.490	35,578
Finished howitzer	8.733	

In the conclusion to his report on gun-bronze Major Wade says: "The general results which are exhibited in this report, on the qualities of bronze as they are found in guns, are mostly of a negative character. They expose defects in density and strength, develop the heterogeneous texture of the metal in different parts of the same gun, and show the irregularity and uncertainty of quality which attend the casting of all guns, although made from similar materials, treated in like manner. The ascertained facts which this report exhibits, although they relate chiefly to existing imperfections in the art of manufacturing bronze, will, it is believed, be found useful. They may serve to awaken the attention of those who may henceforth be concerned in conducting this branch of service, and to suggest such improved methods of treating the materials as will ultimately raise our knowledge of the art to an equality with that which has been attained in the manufacture of iron cannon."

That the strength of ordinary ordnance-bronze is still variable, twenty years after Major Wade's report was written, is shown by the following records of twelve tests made by the Ordnance Department, United States Navy, and furnished to the writer by Capt. William N. Jeffers, United States Navy, Chief of the Bureau of Ordnance.

Navy ordnance-bronze tested in 1875 *and* 1876 *at Washington, D. C.*

Mark.	Tensile strength per square inch of—		Permanent elongation in parts of original length.	Permanent reduction of area in parts of original.	Specific gravity.	
	Original section.	Fractured section.				
M 1, 3-4-75	42,037	70,000	.4795	.40	....	
M 2, 3-4-75	41,768	71,600	.478	.417	....	
BB, IX	22,385	....	.100	....	....	Full of large tin spots.
M 2, 5-6-75	45,737	....	.522	.470	....	
No. 3, 8-21-75	49,772	65,600	.2603	.240	8.878	Cast in chill mold.
No. 2, 8-21-75	48,000	60,000	.211	.20	....	Cast in chill mold.
GB 2, 5-6-75	35,820	....	.4975	.50	....	
GB 8, 5-6-75	29,818	....	.0291	....	8.892	Flaw in the breaking portion.
B 3 L, 12-70-75	33,630	39,000	.135	.134	....	Cast in chill mold.
M 1 C, 3-11-76	51,459	91,600	.580	.438	....	
B 2 C, 3-11-76	45,837	73,450	.396	.376	....	Cast in chill mold.
B 3 C, 3-11-76	44,869	71,600	.415	.373	8.853	Cast in chill mold.

The guns cast in chill molds were composed of 10 parts of copper to 1 part of tin; the others were of 9 parts of copper to 1 part of tin.

That a great improvement may be made in the density and tenacity of gun-bronze by compression has been shown by the experiments of Mr. S. B. Dean, in Boston, Mass., in 1869, and by those of General Uchatius, in Austria,* in 1873. The former increased the density of the metal next the bore of the gun from 8.321 to 8.875, and the tenacity from 27,238 to 41,471 pounds per square inch. The latter by a similar process obtained the following figures for tenacity:

	Pounds per square inch.
Bronze with 10 per cent. tin	72,053
Bronze with 8 per cent. tin	73,958
Bronze with 6 per cent. tin	77,656

The density of these specimens is not given, but it probably approaches very closely to 8.95. It is believed that the experiments of General Uchatius are still in progress.

The experiments of Riche have also shown the increase of density by compression and tempering. A translation of his paper on this subject is given in the appendix.

The table of comparison of authorities is by no means complete. No account is taken of a vast number of ancient bronzes, weapons, medals, coins, and sonorous instruments, which have been described by various writers. These, however, differ but little in composition and properties from the ordnance and bell metal given in the tables.

It will be observed that while there is considerable irregularity in the tenacity of the alloys containing more than 27.5 per cent. of tin, they are all extremely weak, the highest strength found by any experimenter being only 8,736 pounds, and valueless for all purposes in which strength is required.

It has been shown that the useful alloys, those which contain less than 27.5 per cent. of tin, have strengths which are nearly proportional to their densities. A systematic investigation remains yet to be made to ascertain the various causes which operate to produce the blow-holes which are the principal cause of the lack of density, and the means which may be taken to prevent the operation of these causes.

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*Ordnance Notes No. XL, Washington, D. C., 1876.

As before stated, compression of the metal, either in the fluid state or after it has solidified, increases the density and consequently the strength, by closing the blow-holes and compressing the gas which the blow-holes contain.

If the formation of the gas which causes these blow-holes can be prevented, or if it can be removed from the metal while the latter is still in a fluid state, it is evident that the cast metal will be entirely free from them, and a metal of greater density and strength will be obtained which may not need further compression.

No means has yet been discovered by which this desirable result may be accomplished, but it is not improbable that it may be done by a proper system of treatment of the fluid metal, or by the use of fluxes which shall chemically unite with the gas of the blow-holes and prevent its existence in the gaseous state. The subject offers a fruitful field for experiment, one which it is proposed to explore after concluding the researches in progress on castings of copper-tin, copper-zinc, and triple alloys.

[*First series.*]

RECORD OF TESTS BY TRANSVERSE STRESS.

MECHANICAL LABORATORY, DEPARTMENT OF ENGINEERING, STEVENS INSTITUTE OF TECHNOLOGY.

TABLE XXI.—CAST COPPER.

Original mark: No. 1.—**Material**: Copper, cast in hot iron mold.—**Dimensions**: Length between supports, $l=22''$. Breadth, $b=0.994''$. Depth, $d=1.010''$.

Load.	Deflection Δ	Set.	Modulus of elasticity. $E=\frac{l^3}{4\Delta bd^3}(P+4)$
Pounds.	*Inches.*	*Inches.*	
7	0.004		
12	0.006		
20	0.006		
30	0.008		
0		0.0024	
40	0.010		
50	0.009		
60	0.009		
70	0.016		
80	0.018		
90	0.022		
100	0.026		
0		0.007	
125	0.022		15,241,676
150	0.027		14,825,955
0		0.005	
200	0.038		13,986,605
225	0.052		
250	0.073		9,044,333
0		0.010	
275	0.085		
0		0.014	
300	0.098		8,063,308
0		0.018	
325	0.109		
0		0.025	
350	0.123		7,481,071
0		0.032	
400	0.154		6,819,069
0		0.054	
450	0.203		5,813,338
0		0.091	
500	0.265		4,943,631
0		0.147	
550	0.348		4,138,055
0		0.223	
550	0.384		
600	0.442		2,940,095
0		0.295	
600	0.534		
In 5 m.	0.543		
625	0.637		
650	0.707		2,404,496
0		0.578	
549	2.306		Broke.

At 650 pounds a crack appeared on the under side of the bar. After reading the set, the bar sank rapidly under 549 pounds, and broke.

Breaking load 650 pounds.

Modulus of rupture, $R=\frac{3}{2}\frac{l}{bd^2}(P+3)=21,251$.

TABLE XXII.—ALLOY OF COPPER AND TIN.

Original mark: No. 2.—**Material**: Alloy.—**Original mixture**: 98.1 Cu, 1.9 Sn.—**Analysis**: 97.89 Cu, 1.98 Sn. Cast in dry sand.—**Dimensions**: Length between supports, 22″. Breadth, 1.011″. Depth, 1.006″.

Load.	Deflection Δ	Set.	Modulus of elasticity.
5	0.008		
10	0.0024		
15	0.0039		
20	0.0055		
30	0.0080		
40	0.0095		
50	0.012		
60	0.013		
70	0.014		
80	0.016		
90	0.017		
100	0.020		13,487,674
0		0.000	
125	0.030		11,153,271
175	0.041		11,824,079
200	0.154		9,798,737
0		0.0095	
225	0.069		8,608,854
250	0.092		7,161,098
0		0.045	
275	0.124		

The deflection increased with time, but the test was continued without stopping.

Load.	Deflection Δ	Set.	Modulus of elasticity.
300	0.202		3,900,516
0		0.136	
325	0.297		
350	0.368		2,496,107
375	0.577		

The deflection increased rapidly with time.

Load.	Deflection Δ	Set.	Modulus of elasticity.
0		0.537	
400	0.836		1,253,455
425	1.120		
0		1.017	
450	1.454		809,838
475	1.762		
In 3 m.	2.053		
0		1.931	
500	2.108		
In 10 m	2.596		
525	2.738		
550	3.147		456,612
In 3 m.	4.305		
575	4.561		

Bar bent rapidly, and slipped through between supports.

Breaking load (considered to be that which causes a deflection of 3½″), 550 pounds.

Modulus of rupture, $R=\frac{3}{2}\frac{l}{bd^2}(P+3)=17,872$.

RECORD OF TESTS BY TRANSVERSE STRESS—Continued.

[*First series.*]

MECHANICAL LABORATORY, DEPARTMENT OF ENGINEERING, STEVENS INSTITUTE OF TECHNOLOGY.

TABLE XXIII.—ALLOY OF COPPER AND TIN.

Original mark: No. 3.—**Material:** Alloy.—**Original mixture:** 96.27 Cu, 3.73 Sn.—**Analysis:** 96.06 Cu, 3.76 Sn.—**Dimensions:** Length between supports, 22". Breadth, 1". Depth, 0.998".

Load.	Deflection Δ	Set.	Modulus of elasticity. $E=\frac{l^3}{4\Delta bd^3}(P+4)$	Load.	Deflection Δ	Set.	Modulus of elasticity. $E=\frac{l^3}{4\Delta bd^3}(P+4)$
Pounds.	*Inches.*	*Inches.*		*Pounds.*	*Inches.*	*Inches.*	
8	0.0008			In 20 m.	0.601		
10	0.0016			In 30 m.	0.618		
12	0.0032			In 40 m.	0.630		
20	0.0047			In 50 m.	0.642		
30	0.007			1 hour.	0.650		
50	0.010			0		0.524	
0		0.0016		700	0.658		
80	0.017			725	0.669		
100	0.021		13,262,817	750	0.701		
120	0.023			In 5 m.	0.846		
150	0.026		15,862,408	In 10 m.	0.890		
0		0.0024		In 20 m.	0.913		
175	0.032		14,980,447	In 25 m.	0.925		
200	0.041		13,825,025	0		0.780	
225	0.015			775	0.946		
250	0.051		13,837,830	800	0.972		1,696,081
0		0.004		In 5 m.	1.217		
275	0.054			In 15 m.	1.264		
300	0.060		13,568,883	0		1.110	
350	0.069		13,739,654	825	1.280		
0		0.006		850	1.323		
375	0.077			In 5 m.	1.583		
400	0.083		13,035,420	In 45 m.	1.732		
0		0.010		15h 45m	1.882		
425	0.085			0		1.713	
450	0.095		12,798,349	875	1.892		
0		0.014		900	1.929		1,255,041
475	0.102			In 5 m.	2.095		
500	0.122		11,063,497	In 15 m.	2.162		
0		0.025		In 30 m.	2.256		
525	0.124			In 45 m.	2.319		
550	0.138		10,751,086	0		2.123	
0		0.042		925	2.335		
575	0.158			950	2.402		
600	0.181		8,936,754	In 5 m.	2.586		
Left 10 m	0.229			In 15 m.	2.662		
In 30 m.	0.244			975	2.713		
In 50 m.	0.252			In 5 m.	2.983		
0		0.108		In 10 m.	3.091		
625	0.268			1,000	3.118		862,341
650	0.287			In 5 m.	3.540		
In 10 m.	0.382			In 15 m.	3.660		
In 20 m.	0.410			In 45 m.	4.102		
In 30 m.	0.421			1h 15m	7.634	Tray reached bottom of supports.	
0		0.302					
675	0.429						
700	0.441		4,275,193				
In 5 m.	0.559						
In 10 m.	0.588						

Breaking load, P=1,000 pounds.

Modulus of rupture, $R=\frac{3}{2}\frac{l}{bd^2}(P+3)=33,282.$

RECORD OF TESTS BY TRANSVERSE STRESS—Continued.

[*First series.*]

MECHANICAL LABORATORY, DEPARTMENT OF ENGINEERING, STEVENS INSTITUTE OF TECHNOLOGY.

TABLE XXIV.—ALLOY OF COPPER AND TIN.

Original mark: No. 4.—**Material:** Alloy.—**Original mixture:** 92.8 Cu, 7.2 Sn.—**Dimensions:** Length between supports, 22''. Breadth, 0.997''. Depth, 1.012''.

Load.	Deflection Δ	Set.	Modulus of elasticity. $E=\frac{l^3}{4\Delta bd^3}(P+4)$
Pounds.	*Inches.*	*Inches.*	
6	0. 0008	....	....
10	0. 0016	....	....
20	0. 0039	....	....
30	0. 007	....	....
40	0. 010	....	....
60	0. 013	....	....
80	0. 017	....	....
100	0. 020	....	13, 896, 305
0	....	0. 000	....
125	0. 024	....	....
150	0. 029	....	13, 680, 575
175	0. 034	....	....
200	0. 041	....	12, 818, 227
0	....	0. 000	....
225	0. 045	....	....
250	0. 052	....	12, 583, 801
0	....	0. 0008	....
275	0. 057	....	....
300	0. 059	....	13, 274, 439
0	....	0. 000	....
325	0. 063	....	....
350	0. 066	....	13, 817, 863
375	0. 072	....	....
400	0. 075	....	13, 877, 197
0	....	0. 000	....
425	0. 079	....	....
450	0. 082	....	14, 263, 420
475	0. 087	....	....
0	....	0. 0016	....
500	0. 095	....	13, 677, 484
0	....	0. 0024	....
525	0. 102	....	....
550	0. 106	....	13, 464, 355
0	....	0. 0032	....
575	0. 112	....	....
0	....	0. 0055	....
600	0. 124	....	12, 548, 648
0	....	0. 0095	....
650	0. 137	....	....
0	....	0. 013	....
700	0. 153	....	11, 853, 945
0	....	0. 020	....
750	0. 173	....	....
800	0. 199	....	10, 408, 413
0	....	0. 049	....
850	0. 232	....	....
900	0. 287	....	8, 114, 620
0	....	0. 116	....
950	0. 348	....	....
In 5 m.	0. 429	....	....
1, 090	0. 491	....	5, 267, 855
In 5 m.	0. 584	....	....
0	....	0. 379	....
1, 050	0. 620	....	....
In 10 m.	0. 781	....	....
1, 100	0. 858	....	3, 814, 847
In 10 m.	1. 031	....	....
0	....	0. 807	....
1, 100	1. 053	....	....
1, 150	1. 155	....	....
In 3 m.	1. 289	....	....
1, 200	1. 384	....	2, 240, 640
In 10 m.	1. 824	....	....
0	....	1. 549	....
1, 200	1. 824	....	....
1, 250	1. 935	....	....
In 10 m.	2. 178	....	....
In 30 m.	2. 281	....	....
15^h 30^m	2. 638	....	....
0	....	2. 343	....
1, 250	2. 639	....	....
1, 300	2. 746	....	1, 223, 372
In 10 m.	2. 911	....	....
In 30 m.	2. 966	....	....
1, 350	3. 226	....	....
In 30 m.	6. 706	Tray reached bottom of supports.	

Breaking load, P=1,350 pounds.

Modulus of rupture, $R=\frac{3}{2}\,\frac{l}{bd^2}(P+8)=43,731.$

In the above table the figures of order of ductility, malleability, hardness, and fusibility (see also Plate XV) are taken from Mallet's experiments on a series of 16 alloys,* the figure 1 representing the maximum and 16 the minimum of the property. The ductility of the brittle metals is represented by Mallet as 0.

The relative ductility given in the table, of the alloys experimented on by the board, is the proportionate extension of the exterior fibers of the pieces tested by torsion as determined by the autographic strain-diagrams. It will be seen that the order of ductility differs widely from that given by Mallet.

The figures of relative hardness, on the authority of Calvert and Johnson (Plate XV), are those obtained by them by means of an indenting tool. The figures are on a scale in which cast iron is rated at 1,000. The word "broke" in this column indicates the fact that the alloy opposite which it occurs broke under the indenting tool, showing that the relative hardness could not be measured, but was considerably greater than that of cast iron.

The figures of specific gravity show a fair agreement among the several authorities in the alloys containing more than 35 per cent. of tin, except those given by Mallet, which are in general very much lower than those by all the other authorities. In the alloys containing less than 35 per cent. of tin there is a wide variation among all the different authorities, Mallet's figures, however, being generally lower than the others. Several of the figures of specific gravity have been selected from Riche's results of experiments on the effects of annealing, tempering, and compression, which shows that the latter especially tends to increase the specific gravity of all the alloys containing less than 20 per cent. tin to about 8.95. This result, as stated in the discussion on specific gravity (page 355), is due merely to the closing up of the blowholes, and thus diminishing the porosity. The specific gravity of 8.953 was obtained by Major Wade by casting a small bar in a cold iron mold from the same metal which gave a specific gravity of only 8.313 when cast in the form of a small bar in a clay mold. The former result is exceptionally high, and indicates, the probability that every circumstance of the melting, pouring, casting, and cooling was favorable to the exclusion of the gas which forms blowholes, and to the formation of a perfectly compact metal.

Plate XII gives a comparison of the figures of specific gravity obtained by different experimenters.

The figures of tenacity given by Mallet, Muschenbroek, and Wade agree with those found in the experiments described in this report as closely as could be expected from the very variable strengths of alloys of the same composition which have been found by all experimenters.

Mallet's figure for copper, 24.6 tons or 55,104 pounds, is certainly much too high for cast copper; the piece which he tested was probably rolled or perhaps drawn into wire. Haswell's Pocket Book gives the following as the tensile strength of copper; the names of the authorities are not given:

	Pounds per square inch.
Copper, wrought	34,000
Copper rolled	36,000
Copper, cast (American)	24,250
Copper, wire	61,200
Copper, bolt	36,800

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* See appendix.

The figure for cast American copper is evidently taken from the experiments of Major Wade.

The figures obtained by the writer for alloys of 7.5, 10, and 12.5 per cent. tin, viz, 27,900, 26,860, and 31,100 pounds, are much less than is usually given as the strength of gun-metal. It must be remembered, however, that bronze guns are usually cast under the pressure of a head of metal which tends to increase the strength and density. The strength of the upper part of a gun-casting, or sinking head, is not greater than those of the small bars which have been tested in these experiments. The table shows the figures of Major Wade for the mean density and tenacity of a lot of 83 gun-heads of one composition, and of 12 of another composition, the figures for tenacity being respectively 26,655 and 26,011 pounds per square inch.

The strength of gun-bronze, as found in the guns, is not given in the table, which is designed to compare only the various authorities on the tenacities of the alloys only, as cast under ordinary conditions, and not when compressed, rolled, or cast under pressure.

The following are a few extracts which have been made from the report of Major Wade concerning the strength and density of gun-bronze:

Bronze guns made at Chicopee, Mass., 1850.

	Specific gravity.	Tenacity.
Tin, 1 part	7.297	2,122
Copper, 8 parts (mean of 9 samples)	8.672	24,252
Mean of 83 guns	8.751	......
Mean of 83 gun-heads	8.523	29,655

Extreme variation of six samples from different parts of the same gun (a 32-pounder howitzer): Specific gravity, 8.487 to 8.835; tenacity, 26,428 to 52,192. Extreme variation of all the samples tested: Specific gravity, 8.308 to 8.850; tenacity, 23,108 to 54,531. Extreme variation of all the samples from the gun-heads: Specific gravity, 8.308 to 8.756; tenacity, 23,529 to 35,484.

The materials used in all these castings were of the same quality; they were melted, cast, and cooled in the same manner, and were designed to be similarly treated in all respects.

Bronze guns made at South Boston, Mass., 1850—*12-pounder howitzers. Composition*, 10.71 *parts tin in* 100.

	Specific gravity.	Tenacity.
Mean of 12 gun-heads	8.353	26,011
Mean of 12 small bars cast with gun	8.800	52,253

The small bars were cast in the same mold as the gun and were subjected to the pressure of the sinking head. Major Wade remarks that the great superiority of the small bars over the gun-heads may be attributed to their cooling rapidly at first, and until they become solid, and to their subsequent cooling being retarded by the adjacent liquid mass of metal in the gun-head. The bar is in contact at one end with the gun-head, and any contraction which may occur in it after its solidification is supplied by the liquid metal in the head, with a force due to its column of pressure. This fills all cavities and gives compactness to the bar. The heat in the massive head which joins the bar controls and prolongs its cooling. Small bars, cast in separate molds, are cooled

rapidly from first to last, and the cavities formed during their contraction are not supplied from any separate source. To these circumstances we must attribute their inferiority to the bars cast in the gun-molds.

Three howitzers, Nos. 27, 28, and 29, were cast from the same liquid metal contained in a crane-ladle. No. 27 was cast when the metal was at the highest temperature; No. 28 was cast fifteen minutes later; and No. 29 fourteen minutes after No. 28. The following results were obtained:

Number.	Time of metal in ladle, minutes.	Temperature of metal at casting.	Specific gravity—				Tenacity.		
			Of gun-heads.	Of entire gun.	Of small bars cast in—		Of gun-heads.	Of small bars cast in—	
					Gun-mold.	Separate mold.		Gun-mold.	Separate mold.
27	0	Highest	7.986	8.195	8.686	8.554	17,761	50,973	31,132
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In casting another howitzer, No. 30, small test-bars were cast in separate molds, one of which was of cast iron, to ascertain the effect of sudden cooling, and the others were of clay, similar to the gun-mold. The tests of all the samples from this casting were as follows:

	Specific gravity.	Tenacity.
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Small bars cast separately in clay mold	8.313	25,783
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Gun-head samples	8.490	35,578
Finished howitzer	8.733	

In the conclusion to his report on gun-bronze Major Wade says: "The general results which are exhibited in this report, on the qualities of bronze as they are found in guns, are mostly of a negative character. They expose defects in density and strength, develop the heterogeneous texture of the metal in different parts of the same gun, and show the irregularity and uncertainty of quality which attend the casting of all guns, although made from similar materials, treated in like manner. The ascertained facts which this report exhibits, although they relate chiefly to existing imperfections in the art of manufacturing bronze, will, it is believed, be found useful. They may serve to awaken the attention of those who may henceforth be concerned in conducting this branch of service, and to suggest such improved methods of treating the materials as will ultimately raise our knowledge of the art to an equality with that which has been attained in the manufacture of iron cannon."

That the strength of ordinary ordnance-bronze is still variable, twenty years after Major Wade's report was written, is shown by the following records of twelve tests made by the Ordnance Department, United States Navy, and furnished to the writer by Capt. William N. Jeffers, United States Navy, Chief of the Bureau of Ordnance.

The figure for cast American copper is evidently taken from the experiments of Major Wade.

The figures obtained by the writer for alloys of 7.5, 10, and 12.5 per cent. tin, viz, 27,900, 26,860, and 31,100 pounds, are much less than is usually given as the strength of gun-metal. It must be remembered, however, that bronze guns are usually cast under the pressure of a head of metal which tends to increase the strength and density. The strength of the upper part of a gun-casting, or sinking head, is not greater than those of the small bars which have been tested in these experiments. The table shows the figures of Major Wade for the mean density and tenacity of a lot of 83 gun-heads of one composition, and of 12 of another composition, the figures for tenacity being respectively 26,655 and 26,011 pounds per square inch.

The strength of gun-bronze, as found in the guns, is not given in the table, which is designed to compare only the various authorities on the tenacities of the alloys only, as cast under ordinary conditions, and not when compressed, rolled, or cast under pressure.

The following are a few extracts which have been made from the report of Major Wade concerning the strength and density of gun-bronze:

Bronze guns made at Chicopee, Mass., 1850.

	Specific gravity.	Tenacity.
Tin, 1 part	7.297	2,122
Copper, 8 parts (mean of 9 samples)	8.672	24,252
Mean of 83 guns	8.751	......
Mean of 83 gun-heads	8.523	29,655

Extreme variation of six samples from different parts of the same gun (a 32-pounder howitzer): Specific gravity, 8.487 to 8.835; tenacity, 26,428 to 52,192. Extreme variation of all the samples tested: Specific gravity, 8.308 to 8.850; tenacity, 23,108 to 54,531. Extreme variation of all the samples from the gun-heads: Specific gravity, 8.308 to 8.756; tenacity, 23,529 to 35,484.

The materials used in all these castings were of the same quality; they were melted, cast, and cooled in the same manner, and were designed to be similarly treated in all respects.

Bronze guns made at South Boston, Mass., 1850—12-*pounder howitzers. Composition*, 10.71 *parts tin in* 100.

	Specific gravity.	Tenacity.
Mean of 12 gun-heads	8.353	26,011
Mean of 12 small bars cast with gun	8.800	52,253

The small bars were cast in the same mold as the gun and were subjected to the pressure of the sinking head. Major Wade remarks that the great superiority of the small bars over the gun-heads may be attributed to their cooling rapidly at first, and until they become solid, and to their subsequent cooling being retarded by the adjacent liquid mass of metal in the gun-head. The bar is in contact at one end with the gun-head, and any contraction which may occur in it after its solidification is supplied by the liquid metal in the head, with a force due to its column of pressure. This fills all cavities and gives compactness to the bar. The heat in the massive head which joins the bar controls and prolongs its cooling. Small bars, cast in separate molds, are cooled

As before stated, compression of the metal, either in the fluid state or after it has solidified, increases the density and consequently the strength, by closing the blow-holes and compressing the gas which the blow-holes contain.

If the formation of the gas which causes these blow-holes can be prevented, or if it can be removed from the metal while the latter is still in a fluid state, it is evident that the cast metal will be entirely free from them, and a metal of greater density and strength will be obtained which may not need further compression.

No means has yet been discovered by which this desirable result may be accomplished, but it is not improbable that it may be done by a proper system of treatment of the fluid metal, or by the use of fluxes which shall chemically unite with the gas of the blow-holes and prevent its existence in the gaseous state. The subject offers a fruitful field for experiment, one which it is proposed to explore after concluding the researches in progress on castings of copper-tin, copper-zinc, and triple alloys.

Navy ordnance-bronze tested in 1875 *and* 1876 *at Washington, D. C.*

Mark.	Tensile strength per square inch of—		Permanent elongation in parts of original length.	Permanent reduction of area in parts of original.	Specific gravity.	
	Original section.	Fractured section.				
M 1, 3-4-75	42,037	70,000	.4795	.40	....	
M 2, 3-4-75	41,768	71,600	.478	.417	....	
BB, IX	22,385	....	.100	....	....	Full of large tin spots.
M 2, 5-6-75	45,737	....	.522	.470	....	
No. 3, 8-21-75	49,772	65,600	,2603	.240	8.878	Cast in chill mold.
No. 2, 8-21-75	48,000	60,000	.211	.20	....	Cast in chill mold.
GB 2, 5-6-75	35,820	....	.4975	.50	....	
GB 3, 5-6-75	29,818	....	.0291	....	8.392	Flaw in the breaking portion.
B 3 L, 12-70-75	33,630	39,000	.135	.134	....	Cast in chill mold.
M 1 C, 3-11-76	51,459	91,600	.580	.438	....	
B 2 C, 3-11-76	45,837	73,450	.396	.376	....	Cast in chill mold.
B 3 C, 3-11-76	44,869	71,600	.415	.373	8.853	Cast in chill mold.

The guns cast in chill molds were composed of 10 parts of copper to 1 part of tin; the others were of 9 parts of copper to 1 part of tin.

That a great improvement may be made in the density and tenacity of gun-bronze by compression has been shown by the experiments of Mr. S. B. Dean, in Boston, Mass., in 1869, and by those of General Uchatius, in Austria,* in 1873. The former increased the density of the metal next the bore of the gun from 8.321 to 8.875, and the tenacity from 27,238 to 41,471 pounds per square inch. The latter by a similar process obtained the following figures for tenacity:

	Pounds per square inch.
Bronze with 10 per cent. tin	72,053
Bronze with 8 per cent. tin	73,958
Bronze with 6 per cent. tin	77,656

The density of these specimens is not given, but it probably approaches very closely to 8.95. It is believed that the experiments of General Uchatius are still in progress.

The experiments of Riche have also shown the increase of density by compression and tempering. A translation of his paper on this subject is given in the appendix.

The table of comparison of authorities is by no means complete. No account is taken of a vast number of ancient bronzes, weapons, medals, coins, and sonorous instruments, which have been described by various writers. These, however, differ but little in composition and properties from the ordnance and bell metal given in the tables.

It will be observed that while there is considerable irregularity in the tenacity of the alloys containing more than 27.5 per cent. of tin, they are all extremely weak, the highest strength found by any experimenter being only 8,736 pounds, and valueless for all purposes in which strength is required.

It has been shown that the useful alloys, those which contain less than 27.5 per cent. of tin, have strengths which are nearly proportional to their densities. A systematic investigation remains yet to be made to ascertain the various causes which operate to produce the blow-holes which are the principal cause of the lack of density, and the means which may be taken to prevent the operation of these causes.

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*Ordnance Notes No. XL, Washington, D. C., 1876.

As before stated, compression of the metal, either in the fluid state or after it has solidified, increases the density and consequently the strength, by closing the blow-holes and compressing the gas which the blow-holes contain.

If the formation of the gas which causes these blow-holes can be prevented, or if it can be removed from the metal while the latter is still in a fluid state, it is evident that the cast metal will be entirely free from them, and a metal of greater density and strength will be obtained which may not need further compression.

No means has yet been discovered by which this desirable result may be accomplished, but it is not improbable that it may be done by a proper system of treatment of the fluid metal, or by the use of fluxes which shall chemically unite with the gas of the blow-holes and prevent its existence in the gaseous state. The subject offers a fruitful field for experiment, one which it is proposed to explore after concluding the researches in progress on castings of copper-tin, copper-zinc, and triple alloys.

TABLE XX:—PROPERTIES OF THE ALLOYS OF COPPER AND TIN.

COMPARISON OF SEVERAL AUTHORITIES—Continued.

Number.	Atomic formula.	Composition of original mixture.		Composition by analysis.		Specific gravity.	Color.	Fracture.	Tenacity, pounds per square inch.	Order of ductility (Mallet).	Relative ductility (Thurston).	Hardness (Mallet, and Calvert and Johnson).	Order of malleability (Mallet).	Order of fusibility (Mallet).	Conductivity for heat, silver=100.	Conductivity for electricity, silver=100.	Authority.	Remarks.
		Cu.	Sn.	Cu.	Sn.													
146	Sn_3Cu	15.21	84.79			7.606						104.17			42.3		C. J.	
147	Sn_3Cu	15.19	84.81	15.08	84.62	7.657	Grayish white	Crystal	6,520		0.92						T.	
148	Sn_3Cu	15.17	84.83			7.447	do	Coarse crystal.	6,944	0		13	15	4			Ml.	
149		12.50	87.50			7.543	do	Crystal	3,798		4.71						T.	
150	Sn_4Cu	11.86	88.14			7.558						95.81			40.6		C. J.	
151	Sn_4Cu	11.84	88.16	11.49	88.47	7.552	Grayish white	Crystal	6,380		7.08						T.	
152	Sn_4Cu	11.84	88.16			7.50											Ri.	
153	Sn_4Cu	11.82	88.18			7.472	Grayish white	Coarse crystal.	6,944	8		14	4	3			Ml.	
154	Sn_5Cu	9.73	90.27			7.517						83.33			39.6		C. J.	
155	Sn_5Cu	9.73	90.27			7.52											Ri.	
156	Sn_5Cu	9.70	90.30	8.57	91.39	7.487	Grayish white	Granular	6,450		23.47						T.	
157	Sn_5Cu	9.68	90.32			7.442	do	Earthy	3,360	6		15	3	2			Ml.	
158		9.09	90.91			7.472											W.	Slightly malleable.
159		7.50	92.50			7.417	Grayish white	Granular	6,096		40.06						U. S. B.	
160		6.43	93.57													12.03	Ma.	
161	Sn_{12}Cu	4.29	95.71	3.72	96.31	7.360	Grayish white	Granular	4,780		56.77						U. S. B.	
162		2.50	97.50			7.342	do	Fibrous	5,600		121.9						U. S. B.	
163	Sn_{48}Cu	1.11	98.89	0.74	99.02	7.305	do	do	3,650		133.9						U. S. B.	
164	Sn_{96}Cu	0.56	99.44	0.32	99.46	7.299	do	do	4,475		208.8						U. S. B.	
165	Sn	0	100			7.293	do	do	3,500		219.8						U. S. B.	
166		0	100			7.291	White	do	6,040	7		16	1	1			Ml.	
167		0	100			7.297			2,122								Wa.	
168		0	100			7.294										11.45	Ma.	
169		0	100			7.305											Cr.	
170		0	100									27			42.2		C. J.	
171		0	100												15.2	17.0	We.	

In the above table the figures of order of ductility, malleability, hardness, and fusibility (see also Plate XV) are taken from Mallet's experiments on a series of 16 alloys,* the figure 1 representing the maximum and 16 the minimum of the property. The ductility of the brittle metals is represented by Mallet as 0.

The relative ductility given in the table, of the alloys experimented on by the board, is the proportionate extension of the exterior fibers of the pieces tested by torsion as determined by the autographic strain-diagrams. It will be seen that the order of ductility differs widely from that given by Mallet.

The figures of relative hardness, on the authority of Calvert and Johnson (Plate XV), are those obtained by them by means of an indenting tool. The figures are on a scale in which cast iron is rated at 1,000. The word "broke" in this column indicates the fact that the alloy opposite which it occurs broke under the indenting tool, showing that the relative hardness could not be measured, but was considerably greater than that of cast iron.

The figures of specific gravity show a fair agreement among the several authorities in the alloys containing more than 35 per cent. of tin, except those given by Mallet, which are in general very much lower than those by all the other authorities. In the alloys containing less than 35 per cent. of tin there is a wide variation among all the different authorities, Mallet's figures, however, being generally lower than the others. Several of the figures of specific gravity have been selected from Riche's results of experiments on the effects of annealing, tempering, and compression, which shows that the latter especially tends to increase the specific gravity of all the alloys containing less than 20 per cent. tin to about 8.95. This result, as stated in the discussion on specific gravity (page 355), is due merely to the closing up of the blowholes, and thus diminishing the porosity. The specific gravity of 8.953 was obtained by Major Wade by casting a small bar in a cold iron mold from the same metal which gave a specific gravity of only 8.313 when cast in the form of a small bar in a clay mold. The former result is exceptionally high, and indicates, the probability that every circumstance of the melting, pouring, casting, and cooling was favorable to the exclusion of the gas which forms blowholes, and to the formation of a perfectly compact metal.

Plate XII gives a comparison of the figures of specific gravity obtained by different experimenters.

The figures of tenacity given by Mallet, Muschenbroek, and Wade agree with those found in the experiments described in this report as closely as could be expected from the very variable strengths of alloys of the same composition which have been found by all experimenters.

Mallet's figure for copper, 24.6 tons or 55,104 pounds, is certainly much too high for cast copper; the piece which he tested was probably rolled or perhaps drawn into wire. Haswell's Pocket Book gives the following as the tensile strength of copper; the names of the authorities are not given:

	Pounds per square inch.
Copper, wrought	34,000
Copper rolled	36,000
Copper, cast (American)	24,250
Copper, wire	61,200
Copper, bolt	36,800

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* See appendix.

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The figures obtained by the writer for alloys of 7.5, 10, and 12.5 per cent. tin, viz, 27,900, 26,860, and 31,100 pounds, are much less than is usually given as the strength of gun-metal. It must be remembered, however, that bronze guns are usually cast under the pressure of a head of metal which tends to increase the strength and density. The strength of the upper part of a gun-casting, or sinking head, is not greater than those of the small bars which have been tested in these experiments. The table shows the figures of Major Wade for the mean density and tenacity of a lot of 83 gun-heads of one composition, and of 12 of another composition, the figures for tenacity being respectively 26,655 and 26,011 pounds per square inch.

The strength of gun-bronze, as found in the guns, is not given in the table, which is designed to compare only the various authorities on the tenacities of the alloys only, as cast under ordinary conditions, and not when compressed, rolled, or cast under pressure.

The following are a few extracts which have been made from the report of Major Wade concerning the strength and density of gun-bronze:

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Mean of 83 gun-heads	8.523	29,655

Extreme variation of six samples from different parts of the same gun (a 32-pounder howitzer): Specific gravity, 8.487 to 8.835; tenacity, 26,428 to 52,192. Extreme variation of all the samples tested: Specific gravity, 8.308 to 8.850; tenacity, 23,108 to 54,531. Extreme variation of all the samples from the gun-heads: Specific gravity, 8.308 to 8.756; tenacity, 23,529 to 35,484.

The materials used in all these castings were of the same quality; they were melted, cast, and cooled in the same manner, and were designed to be similarly treated in all respects.

Bronze guns made at South Boston, Mass., 1850—12-*pounder howitzers. Composition*, 10.71 *parts tin in* 100.

	Specific gravity.	Tenacity.
Mean of 12 gun-heads	8.353	26,011
Mean of 12 small bars cast with gun	8.800	52,253

The small bars were cast in the same mold as the gun and were subjected to the pressure of the sinking head. Major Wade remarks that the great superiority of the small bars over the gun-heads may be attributed to their cooling rapidly at first, and until they become solid, and to their subsequent cooling being retarded by the adjacent liquid mass of metal in the gun-head. The bar is in contact at one end with the gun-head, and any contraction which may occur in it after its solidification is supplied by the liquid metal in the head, with a force due to its column of pressure. This fills all cavities and gives compactness to the bar. The heat in the massive head which joins the bar controls and prolongs its cooling. Small bars, cast in separate molds, are cooled

rapidly from first to last, and the cavities formed during their contraction are not supplied from any separate source. To these circumstances we must attribute their inferiority to the bars cast in the gun-molds.

Three howitzers, Nos. 27, 28, and 29, were cast from the same liquid metal contained in a crane-ladle. No. 27 was cast when the metal was at the highest temperature; No. 28 was cast fifteen minutes later; and No. 29 fourteen minutes after No. 28. The following results were obtained:

Number.	Time of metal in ladle, minutes.	Temperature of metal at casting.	Specific gravity—				Tenacity.		
			Of gun-heads.	Of entire gun.	Of small bars cast in—		Of gun-heads.	Of small bars cast in—	
					Gun-mold.	Separate mold.		Gun-mold.	Separate mold.
27	0	Highest	7.986	8.195	8.686	8.554	17,761	50,973	31,132
28	15	Mean	8.351	8.551	8.823	8.447	28,995	52,330	28,153
29	29	Lowest	8.538	8.752	8.846	8.876	23,722	56,786	28,082

In casting another howitzer, No. 30, small test-bars were cast in separate molds, one of which was of cast iron, to ascertain the effect of sudden cooling, and the others were of clay, similar to the gun-mold. The tests of all the samples from this casting were as follows:

	Specific gravity.	Tenacity.
Small bars cast separately in iron mold	8.953	37,688
Small bars cast separately in clay mold	8.313	25,783
Small bars cast in gun-mold	8.896	53,798
Gun-head samples	8.490	35,578
Finished howitzer	8.733	

In the conclusion to his report on gun-bronze Major Wade says: "The general results which are exhibited in this report, on the qualities of bronze as they are found in guns, are mostly of a negative character. They expose defects in density and strength, develop the heterogeneous texture of the metal in different parts of the same gun, and show the irregularity and uncertainty of quality which attend the casting of all guns, although made from similar materials, treated in like manner. The ascertained facts which this report exhibits, although they relate chiefly to existing imperfections in the art of manufacturing bronze, will, it is believed, be found useful. They may serve to awaken the attention of those who may henceforth be concerned in conducting this branch of service, and to suggest such improved methods of treating the materials as will ultimately raise our knowledge of the art to an equality with that which has been attained in the manufacture of iron cannon."

That the strength of ordinary ordnance-bronze is still variable, twenty years after Major Wade's report was written, is shown by the following records of twelve tests made by the Ordnance Department, United States Navy, and furnished to the writer by Capt. William N. Jeffers, United States Navy, Chief of the Bureau of Ordnance.

RECORD OF TESTS BY TENSILE STRESS.

[*First series.*]

MECHANICAL LABORATORY, DEPARTMENT OF ENGINEERING, STEVENS INSTITUTE OF TECHNOLOGY.

TABLE LI.—CAST COPPER.

Original mark: No. 1 A.—**Material:** Cast copper.—**Dimensions:** Length, 6″. Diameter, 0.798″.

Load.	Load per square inch.	Elongation in 5 inches.	Elongation in parts of original length.
Pounds.	*Pounds.*	*Inches.*	
5,900	11,800	0.01	.0020
6,825	13,650	0.03	.0060
7,090	14,180	0.03	....

Broke ¼ inch from end marked C.

Diameter of fractured section, 0.790 inch.

Several blowholes in section; estimated area of blowholes, 0.053 square inch.

Tenacity per square inch original section, 14,180 pounds.

Tenacity per square inch, deducting blowholes, 15,865 pounds.

Tenacity per square inch in fractured section, 14,464 pounds.

TABLE LII.—CAST COPPER.

Original mark: No, 1 B.—**Material:** Cast copper.—**Dimensions:** Length, 6″. Diameter, .9798″.

Load.	Load per square inch.	Elongation in 5.99 inches.	Elongation in parts of original length.
Pounds.	*Pounds.*	*Inches.*	
4,550	9,100	0.01	.0017
5,670	11,340	0.02	.0033

Broke about 20 seconds after strain was applied ¼ inch from B end.

Diameter of fractured section, 0.792 inch.

Estimated area of blowholes in section, 0.0575 square inch.

Tenacity per square inch in original section, 11,340 pounds.

Tenacity per square inch, deducting blowholes, 12,814 pounds.

Tenacity per square inch in fractured section, 11,509 pounds.

TABLE LIII.—ALLOY OF COPPER AND TIN.

Original mark: No. 2 A.—**Material:** Alloy.—**Original mixture:** 98.1 Cu, 1.9 Sn.—**Analysis:** 97.95 Cu, 1.88 Sn.—**Dimensions:** Length, 5″. Diameter, 0.798″.

Load.	Load per square inch.	Elongation in 4.98 inches.	Elongation in parts of original length.
Pounds.	*Pounds.*	*Inches.*	
4,310	8,620	0.01	.0020
5,110	10,220	0.02	.0040
5,390	10,780	0.03	.0060
5,700	11,400	0.04	.0080
6,350	12,700	0.06	.0120
0	......	Set 0.05	....
6,800	13,600	0.08	.0160
7,250	14,500	0.11	.0220
7,570	15,140	0.14	.0281
8,300	16,600	0.22	.0442
8,960	17,920	0.27	.0542
9,450	18,900	0.31	.0623
10,000	20,000	0.38	.0763
10,800	21,600	0.49	.0984
11,600	23,200	0.56	.1125
12,000	24,000	0.62	.1245
12,600	25,200	0.78	.1566

Broke at A end.

At 10,800 the elongation was observed to increase with time.

Diameter of fractured section, 0.730 inch.

A large number of blowholes in the fractured section, but their size was too small to be measured.

Tenacity per square inch original section, 25,200 pounds.

Tenacity per square inch fractured section, 30,104 pounds.

RECORD OF TESTS BY TENSILE STRESS—Continued.

[*First series.*]

MECHANICAL LABORATORY, DEPARTMENT OF ENGINEERING, STEVENS INSTITUTE OF TECHNOLOGY.

TABLE LIV.—ALLOY OF COPPER AND TIN.

Original mark: No. 2 B.—**Material:** Alloy.—**Original mixture:** 98.1 Cu, 1.9. Sn.—**Analysis:** 97.83 Cu, 1.92 Sn.—**Dimensions:** Length, 4⅜″. Diameter, 0.798″.

Load.	Load per square inch.	Elongation in 4 inches.	Elongation in parts of original length.
Pounds.	*Pounds.*	*Inches.*	
4, 725	9, 450	0. 01	.0025
6, 100	12, 200	0. 03	.0075
6, 560	13, 120	0. 04	.0100
6, 990	13, 980	0. 06	.0150
7, 520	15, 040	0. 10	.0250
0	....	Set 0. 10	....
7, 860	15, 720	0. 11	.0275
8, 220	16, 440	0. 13	.0325
8, 930	17, 860	0. 16	.0400
9, 270	18, 540	0. 20	.0500
9, 875	19, 750	0. 24	.0600
10, 610	21, 220	0. 30	.0750
11, 250	22, 500	0. 35	.0875
11, 690	23, 380	0. 40	.1000
11, 980	23, 960	0. 44	.1100

Broke 1⅜ inches from B end.

Fractured section, elliptical diameters, 0.717 and 0.730 inch.

One blowhole, area 0.059 square inch; the rest of the surface free.

Tenacity per square inch of original section, 23,960 pounds.

Tenacity per square inch, deducting blowhole, 27,166 pounds.

Tenacity per square inch in fractured section, 29,142 pounds.

TABLE LV.—ALLOY OF COPPER AND TIN.

Original mark: No. 3 A.—**Material:** Alloy.—**Original mixture:** 96.27 Cu, 3.73 Sn.—**Analysis:** 96.16 Cu, 3.71 Sn.—**Dimensions:** Length, 6″. Diameter, 0.798″.

Load.	Load per square inch.	Elongation in 6 inches.	Elongation in parts of original length.
Pounds.	*Pounds.*	*Inches.*	
6, 000	12, 000	0. 01	.0017
7, 850	15, 700	0. 02	.0033
9, 200	18, 400	0. 06	.0100
9, 850	19, 700	0. 10	.0167
0	....	Set 0. 09	....
11, 000	22, 000	0. 18	.0300
11, 580	23, 160	0. 24	.0400
12, 000	24, 000	0. 29	.0483
12, 530	25, 060	0. 36	.0600
13, 150	26, 300	0. 40	.0667
In 1 m.	....	0. 45	.0750
13, 780	27, 560	0. 48	.0800
14, 150	28, 300	0. 54	.0900
14, 650	29, 300	0. 61	.1017
15, 200	30, 400	0. 70	.1167
15, 480	30, 960	0. 79	.1317

Broke 1⅛ inches from C end.

Diameter of fractured section, 0.696 inch.

One blowhole in center of specimen, extending through about 3 inches of its length. Area of blowhole at fractured section, 0.076 square inch.

Tenacity per square inch original section, 30,960 pounds.

Tenacity per square inch, deducting blowhole, 36,509 pounds.

Tenacity per square inch fractured section, 40, 687 pounds.

TABLE LVI.—ALLOY OF COPPER AND TIN.

Original mark: No. 3 B.—**Material:** Alloy.—**Original mixture:** 96.27 Cu, 3.73 Sn.—**Analysis:** 95.96 Cu, 3.80 Sn.—**Dimensions:** Length, 5⅛″. Diameter, 0.798″.

Load.	Load per square inch.	Elongation in 5 inches.	Elongation in parts of original length.
Pounds.	*Pounds.*	*Inches.*	
6, 050	12, 100	0. 01	.0020
8, 120	16, 240	0. 03	.0060
10, 000	20, 000	0. 05	.0100
0	....	Set 0. 04	....
10, 850	21, 700	0. 08	.0160
11, 550	23, 100	0. 12	.0240
12, 340	24, 680	0. 19	.0380
12, 950	25, 900	0. 24	.0480
13, 450	26, 900	0. 30	.0600
13, 880	27, 760	0. 34	.0680
14, 440	28, 880	0. 39	.0780
15, 000	30, 000	0. 46	.0920
15, 500	31, 000	0. 52	.1040
16, 000	32, 000	0. 62	.1240
16, 400	32, 800	0. 68	.1360
16, 520	33, 040	0. 77	.1540

Broke in middle.

Diameter of fractured section, 0.686 inch.

Two blowholes in surface of fracture. Area, 0.0295 square inch.

Tenacity per square inch original section, 33,040 pounds.

Tenacity per square inch, deducting blowholes, 35,112 pounds.

Tenacity per square inch fractured section, 44,696 pounds.

RECORD OF TESTS BY TENSILE STRESS—Continued.

[*First series.*]

MECHANICAL LABORATORY, DEPARTMENT OF ENGINEERING, STEVENS INSTITUTE OF TECHNOLOGY.

TABLE LVII.—ALLOY OF COPPER AND TIN.

Original mark: No. 4 A.—**Material:** Alloy.—**Original mixture:** 92.8 Cu, 7.2 Sn.—**Analysis:** 92.14 Cu, 7.84 Sn.—**Dimensions:** Length, 5'. Diameter, 0.798".

Load.	Load per square inch.	Elongation in 5 inches.	Elongation in parts of original length.
Pounds.	*Pounds.*	*Inches.*	
5, 100	10, 200	0. 01	. 0020
8, 000	16, 000	0. 02	. 0040
10, 000	20, 000	0. 03	. 0060
10, 760	21, 520	0. 05	. 0100
11, 410	22, 820	0. 09	. 0180
0		Set 0. 08	
11, 900	23, 800	0. 11	. 0220
12, 800	25, 600	0. 14	. 0280
13, 140	26, 280	0. 21	. 0420
14, 000	28, 000	0. 27	. 0540
14, 610	29, 220	0. 37	. 0740
14, 650	29, 300	0. 39	. 0780

Broke 1¼ inches from C end.

Diameter of fractured section, 0.730 inch. No blowholes.

Tenacity per square inch of original section, 29,300 pounds.

Tenacity per square inch in fractured section, 35,002 pounds.

TABLE LVIII.—ALLOY OF COPPER AND TIN.

Original mark: No. 4 B.—**Material:** Allov.—**Original mixture:** 92.8 Cu, 7.2 Sn.—**Dimensions:** Length, 5¼". Diameter, 0.798."

Load.	Load per square inch.	Elongation in 5.23 inches.	Elongation in parts of original length.
Pounds.	*Pounds.*	*Inches.*	
8, 000	16, 000	0. 01	. 0019
10, 000	20, 000	0. 02	. 0039
11, 000	22, 000	0. 03	. 0057
11, 700	23, 400	0. 05	. 0096
12, 000	24, 000	0. 07	. 0034
0		Set 0. 06	
12, 500	25, 000	0. 09	. 0172
18, 680	27, 360	0. 16	. 0306
13, 890	27, 780	0. 17	. 0325

Broke 1¾ inches from D end.

Diameter of fractured section, 0.737 inch. No blowholes.

Tenacity per square inch of original section, 27,780 pounds.

Tenacity per square inch in fractured section, 32,559 pounds.

TABLE LIX.—ALLOY OF COPPER AND TIN.

Original mark: No. 5 A.—**Material:** Alloy.—**Original mixture:** 90 Cu, 10 Sn.—**Analysis:** 90.11 Cu, 9.66 Sn.—**Dimensions:** Length, 3.4". Diameter, 0.798".

Load.	Load per square inch.	Elongation in 3.4 inches.	Elongation in parts of original length.
Pounds.	*Pounds.*	*Inches.*	
4, 700	9, 400	0. 01	. 0029
7, 640	15, 280	0. 02	. 0059
12, 340	24, 680	0. 06	. 0176
12, 760	25, 520	0. 10	. 0204
13, 260	26, 520	0. 13	. 0384
13, 360	26, 720	0. 14	. 0412

Broke 1½ inches from C end.

Diameter of fractured section, 0.745 inch.

A few very small blowholes.

Tenacity per square inch in original section, 26,720 pounds.

Tenacity per square inch in fractured section, 30,649 pounds.

TABLE LX.—ALLOY OF COPPER AND TIN.

Original mark: No. 5 B.—**Material:** Alloy.—**Original mixture:** 90 Cu, 10 Sn.—**Analysis:** 90.43 Cu, 9.50 Sn.—**Dimensions:** Length, 3.45". Diameter, 0.798".

Load.	Load per square inch.	Elongation in 3.45 inches.	Elongation in parts of original length.
Pounds.	*Pounds.*	*Inches.*	
8, 220	16, 440	0. 01	. 0029
10, 300	20, 600	0. 03	. 0087
11, 075	22, 150	0. 06	. 0174
12, 000	24, 000	0. 07	. 0203
12, 680	25, 360	0. 09	. 0261
0		Set 0. 08	
13, 250	26, 500	0. 11	. 0319
13, 500	27, 000		

Broke at B end.

Diameter of fractured section, 0.760 inch. No blowholes.

Tenacity per square inch in original section, 27,000 pounds.

Tenacity per square inch in fractured section, 29,761 pounds.

RECORD OF TESTS BY TENSILE STRESS—Continued.

[*First series.*]

MECHANICAL LABORATORY, DEPARTMENT OF ENGINEERING, STEVENS INSTITUTE OF TECHNOLOGY.

TABLE LXI.—ALLOY OF COPPER AND TIN.

Original mark: No. 6 A.—Material: Alloy.—Original mixture: 86.57 Cu, 13.43 Sn.—Analysis: 87.15 Cu, 12.69 Sn.—Dimensions: Length, 4⅞″. Diameter, 0.798″.

Load.	Load per square inch.	Elongation in 4.87 inches.	Elongation in parts of original length.
Pounds.	*Pounds.*	*Inches.*	
10,000	20,000	0.01	.0020
12,000	24,000	0.03	.0062
13,200	26,400	0.06	.0123
13,350	26,700	0.09	.0185

Broke ¼ inch from C end.

Diameter of fractured section, 0.792 inch.

One blowhole, elliptical, 0.18 x 0.06 inch diameters.

Tenacity per square inch original section, 26,700 pounds.

Tenacity per square inch deducting blowhole, 27,162 pounds.

Tenacity per square inch fractured section, 27,098 pounds.

TABLE LXII.—ALLOY OF COPPER AND TIN.

Original mark: No. 6 B.—Material: Alloy.—Original mixture: 86.57 Cu, 13.43 Sn.—Analysis: 87.15 Cu, 12.77 Sn.—Dimensions: Length, 5⅝″. Diameter, 0.798″.

Load.	Load per square inch.	Elongation in 5 inches.	Elongation in parts of original length.	Load.	Load per square inch.	Elongation in 5 inches.	Elongation in parts of original length.
Pounds.	*Pounds.*	*Inches.*		*Pounds.*	*Pounds.*	*Inches.*	
7,000	14,000	0.01	.0060	15,580	31,160	0.21	.0420
10,800	21,600	0.02	.0040	16,000	32,000	0.24	.0480
11,000	22,000	0.03	.0060	16,080	33,160	....	....
11,800	23,600	0.04	.0080				
13,050	26,100	0.06	.0120				
13,500	27,000	0.09	.0180				
0	....	Set 0.08	....				
14,000	28,000	0.11	.0220				
14,700	29,400	0.14	.0280				
15,000	30,000	0.18	.0360				
0	....	Set 0.17	....				

Broke 1 inch from D end.

Diameter of fractured section, 0.773 inch. No blowholes.

Tenacity per square inch original section, 32,160 pounds.

Tenacity per square inch fractured section, 34,263 pounds.

TABLE LXIII.—ALLOY OF COPPER AND TIN.

Original mark: No. 7 A.—Material: Alloy.—Original mixture: 80 Cu, 20 Sn.—Analysis: 80.99 Cu, 18.92 Sn.—Dimensions: Length, 6″. Diameter, 0.798″.

9,850	19,700	0.01	.002
14,000	28,000	0.02	.004
16,800	33,600	Broke in middle.	

Diameter of fractured section, 0.798 inch.

One blowhole, irregular-shaped, about 0.10 inch diameter.

Tenacity per square inch original section, 33,600 pounds.

Tenacity per square inch, deducting blowhole, 34,139 pounds.

TABLE LXIV.—ALLOY OF COPPER AND TIN.

Original mark: No. 7 B.—Material: Alloy.—Original mixture: 80 Cu, 20 Sn.—Analysis: 80.90 Cu, 18.75 Sn.—Dimensions: Length, 4⅞″. Diameter, 0.798″.

10,000	20,000	0.01	.002
15,140	30,280	0.02	.004
16,180	32,360	Broke at D end, at the fillet.	

Diameter of fractured section. 0.800 inch.

Tenacity per square inch original section, 32,360 pounds.

TABLE LXV.—ALLOY OF COPPER AND TIN.

Original mark: No. 8 A.—Material: Alloy.—Original mixture: 76.32 Cu, 23.68 Sn.—Analysis: 76.67 Cu, 23.24 Sn.—Dimensions: Length, 6″. Diameter, 0.798″.

Broke at 10,300 pounds at A end.

Elongation just perceptible to touch of calipers.

Several small blowholes. Area about 0.016 square inch.

Tenacity per square inch original section, 20,600 pounds.

Tenacity per square inch, deducting blowholes 21,281 pounds.

RECORD OF TESTS BY TENSILE STRESS—Continued.

[*First series.*]

MECHANICAL LABORATORY, DEPARTMENT OF ENGINEERING, STEVENS INSTITUTE OF TECHNOLOGY.

TABLE LXVI.—ALLOY OF COPPER AND TIN.

Original mark: No. 8 B.—**Material:** Alloy.—**Original mixture:** 76.32 Cu, 23.68 Sn.—**Analysis:** 76.60 Cu, 23.23 Sn.—**Dimensions:** Length, 4½″. Diameter, 0.798″.

Broke at 11,710 pounds, ¼ inch from D end.

No elongation that could be detected.

Tenacity per square inch original section, 23,420 pounds.

TABLE LXVII.—ALLOY OF COPPER AND TIN.

Original mark: No. 9 A.—**Material:** Alloy.—**Original mixture:** 70 Cu, 30 Sn.—**Analysis:** 69.90 Cu, 29.85 Sn.—**Dimensions:** Length of turned portion, 1″. Diameter, 0.965″.

Had difficulty in setting the piece in the jaws of the tensile machine, as the alloy was harder than the steel faces of the jaws.

At 2,600 pounds stress the piece slipped out from the jaws, and again at 4,300 and 1,420 pounds.

Reset each time.

At 6,950 pounds the piece broke in the square portion, 1 inch from the A end of the turned part.

Measurement of fractured section, 1 inch x 0.992 inch.

Tenacity of section fractured, per square inch, 7,006 pounds.

Tenacity of circular section (unbroken), 9,121 pounds *plus*.

TABLE LXVIII.—ALLOY OF COPPER AND TIN.

Original mark: No. 9 B.—**Material:** Alloy.—**Original mixture:** 70 Cu, 30 Sn.—**Analysis:** 69.77 Cu, 29.92 Sn.—**Dimensions:** Length, 1″. Diameter, 0.972″.

Broke in turned portion, at 3,090 pounds.

Tenacity per square inch, 4,164 pounds.

TABLE LXIX.—ALLOY OF COPPER AND TIN.

Original mark: No. 10 B.—**Material:** Alloy.—**Original mixture:** 68.25 Cu, 31.75 Sn.—**Analysis:** 68.57 Cu, 31.30 Sn.—**Dimensions:** Rectangular section, 0.994 x 1.005″. (Too brittle to be turned in lathe.)

Slipped from the jaws of the tensile machine at 500, 650, and 775 pounds.

Broke at 1,620 pounds, in the jaws, ¾ inch from end of piece marked D.

The piece remaining after this test was too short to be tested further in the same machine, and it was sent to Messrs. Rièhlé Bros., Philadelphia, who tested it, and reported its strength at 1,600 pounds per square inch.

Tenacity per square inch, 1,620 pounds.

TABLE LXX.—ALLOY OF COPPER AND TIN.

Original mark: No. 11 A.—**Material:** Alloy.—**Original mixture:** 65 Cu, 35 Sn.—**Analysis:** 65.31 Cu, 34.47 Sn.—**Dimensions:** Length, 1″. Diameter, 0.974″.

Broke in middle, at 1,770 pounds.

Tenacity per square inch, 2,376 pounds.

TABLE LXXI.—ALLOY OF COPPER AND TIN.

Original mark: No. 11 B.—**Material:** Alloy.—**Original mixture:** 65 Cu, 35 Sn.—**Analysis:** 65.36 Cu, 34.47 Sn.—**Dimensions:** Length, 1″. Diameter, 0.975″.

Slipped from jaws of tensile machine, at 1,520, 1,680, and 1,775 pounds.

Broke at 2,025 pounds, in the jaws, ¾ inch from D end, and in the square portion of the specimen.

Tenacity of fractured section per square inch, 2,025 pounds.

Tenacity of turned portion (unbroken), 2,712 pounds *plus*.

TABLE LXXII.—ALLOY OF COPPER AND TIN.

Original mark: No. 12 A.—**Material:** Alloy.—**Original mixture:** 61.71 Cu, 38.29 Sn.—**Dimensions:** Rectangular section, 0.998″ x 1.004″. (Too brittle to be turned.)

The piece 12 A broke in handling into two pieces, marked A and C.

These were sent to Messrs. Rièhlé Bros., Philadelphia, who reported their tenacity to be—

No. 12 A, 250 pounds per square inch.

No. 12 C, 1,125 pounds per square inch.

No. 12 B broke into several pieces while being turned in the lathe.

RECORD OF TESTS BY TENSILE STRESS—Continued.

[*First series.*]

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TABLE LXXIII.—ALLOY OF COPPER AND TIN.

Original mark: No. 13 A.—**Material:** Alloy.—**Original mixture:** 56.32 Cu, 43.68 Sn.—**Analysis:** 56.58 Cu, 3.11 Sn.—**Dimensions:** Length, 1″. Diameter, 0.980″.

Broke at 950 pounds at C end of turned portion.

Tenacity per square inch, 1,259 pounds.

TABLE LXXIV.—ALLOY OF COPPER AND TIN.

Original mark: No. 13 B.—**Material:** Alloy.—**Original mixture:** 56.32 Cu, 43.68 Sn.—**Analysis:** 56.82 Cu, 43.22 Sn.—**Dimensions:** Length, 1″. Diameter, 0.975″.

Broke at 240 pounds, in the square portion of the specimen, 1 inch from the D end of the turned part.

Sent the larger piece remaining to Messrs. Rièhlé Bros., who reported its strength to be 1,650 pounds per square inch, breaking in the turned portion near the shoulder.

TABLE LXXV.—ALLOY OF COPPER AND TIN.

Original mark: No. 14 A.—**Material:** Alloy.—**Original mixture:** 61.8 Cu, 48.2 Sn.—**Analysis:** 62.27 Cu, 37.58 Sn.—**Dimensions:** Length, 1″. Diameter, 0.968″.

Broke in the jaws of machine, in the square portion, ¾ inch from C end, at 1;170 pounds.

Tenacity of section fractured, 1,170 pounds per square inch.

Tenacity of turned portion (unbroken), 1,590 pounds *plus*.

TABLE LXXVI.—ALLOY OF COPPER AND TIN.

Original mark: No. 14 B.—**Material:** Alloy.—**Original mixture:** 51.8 Cu, 48.2 Sn.—**Analysis:** 38.41 Cu, 61.04 Sn.—**Dimensions:** Length, 1″. Diameter, 0.798″.

Broke at 1,970 pounds in middle of turned portion.

Tenacity per square inch, 3,940 pounds.

TABLE LXXVII.—ALLOY OF COPPER AND TIN.

Original mark: No. 15 A.—**Material:** Alloy.—**Original mixture:** 47.95 Cu, 52.025 Sn.—**Analysis:** 47.72 Cu, 51.99 Sn.—**Dimensions:** Section, 1.005″ square.

The piece No. 15 A broke into two pieces in handling.

The broken pieces, marked A and C, were sent to Messrs. Rièhlé Bros., who reported their tenacity to be—

No. 15 A, 900 pounds per square inch.
No. 15 C, 2,100 pounds.

TABLE LXXVIII.—ALLOY OF COPPER AND TIN.

Original mark: No. 15 B.—**Material:** Alloy.—**Analysis:** 47.49 Cu, 52.29 Sn.

This piece broke in the lathe while being turned.

Pieces too short for test.

TABLE LXXIX.—ALLOY OF COPPER AND TIN.

Original mark: No. 16 A.—**Material:** Alloy.—**Original mixture:** 44.63 Cu, 55.37 Sn.—**Analysis:** 44.62 Cu, 55.15 Sn.—**Dimensions:** Length, 1″ Diameter, 0.980″.

Broke at 2,620 pounds in middle of turned part.

Tenacity per square inch, 3,460 pounds.

TABLE LXXX.—ALLOY OF COPPER AND TIN.

Original mark: No. 16 B.—**Material:** Alloy.—**Analysis:** 44.42 Cu, 55.41 Sn.—**Dimensions:** Length, 6″. Diameter, 0.798″.

Broke at 1,280, after the stress had been applied for several seconds, at D end of turned part.

Elongation just perceptible to touch of calipers.

RECORD OF TESTS BY TENSILE STRESS—Continued.

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TABLE LXXXI.—ALLOY OF COPPER AND TIN.

Original mark: No. 17 A.—**Material:** Alloy.—**Original mixture:** 41.74 Cu, 58.26 Sn.—**Analysis:** 45.93 Cu, 53.80 Sn.—**Dimensions:** Length, 6″. Diameter, 0.798″.

Broke at 1,130 pounds ½ inch from A end. No elongation detected.	Tenacity per square inch, 2,260 pounds.

TABLE LXXXII.—ALLOY OF COPPER AND TIN.

Original mark: No. 17 B.—**Material:** Alloy.—**Original mixture:** 41.74 Cu, 58.26 Sn.—**Analysis:** 38.83 Cu, 60.79 Sn.—**Dimensions:** Length, 6″. Diameter, 0.798″.

Broke at 2,780 pounds ½ inch from B end. No elongation.	Tenacity per square inch, 5,560 pounds.

TABLE LXXXIII.—ALLOY OF COPPER AND TIN.

Original mark: No. 18 A.—**Material:** Alloy.—**Original mixture:** 39.20 Cu, 60.80 Sn.—**Analysis (No. 18 C):** 38.37 Cu, 61.32 Sn.—**Dimensions:** Length, 6″. Diameter, 0.798″.

Broke in the tensile-machine before strain was applied, with the weight of the piston and attachments, about 100 pounds.	Tenacity doubtful.

TABLE LXXXIV.—ALLOY OF COPPER AND TIN.

Original mark: No. 18 B.—**Material:** Alloy.—**Analysis (No. 18 C):** 38.37 Cu, 61.32 Sn.—**Dimensions:** Length, 6″. Diameter, 0.798″.

Broke at 1,410 pounds 2½ inches from B end. Elliptical-shaped blowhole in fractured surface. Area, 0.12 square inch.	Tenacity per square inch, 2,820 pounds. Tenacity per square inch, deducting blowhole, 3,711 pounds.

TABLE LXXXV.—ALLOY OF COPPER AND TIN.

Original mark: No. 19 A.—**Material:** Alloy.—**Original mixture:** 34.95 Cu, 65.05 Sn.—**Analysis (No. 19 C):** 34.22 Cu, 65.80 Sn.—**Dimensions:** Length, 6″. Diameter, 0.798″.

Broke 1 inch from A end in the same manner as No. 18 A.	Tenacity doubtful.

TABLE LXXXVI.—ALLOY OF COPPER AND TIN.

Original mark: No. 19 B.—**Material:** Alloy.—**Analysis (No. 19 C):** 34.22 Cu, 65.80 Sn.—**Dimensions:** Length, 6″. Diameter, 0.799″.

Broke 1 inch from D end at 1,690 pounds.	Tenacity per square inch, 3,371 pounds.

TABLE LXXXVII.—ALLOY OF COPPER AND TIN.

Original mark: No. 20 A.—**Material:** Alloy.—**Original mixture:** 38.72 Cu, 71.28 Sn.—**Analysis:** 26.57 Cu, 73.06 Sn.—**Dimensions:** Length, 6″. Diameter, 0.799″.

Broke at 900 pounds 2 inches from C end.	Tenacity per square inch, 1,795 pounds.

TABLE LXXXVIII.—ALLOY OF COPPER AND TIN.

Original mark: No. 20 B.—**Material:** Alloy.—**Original mixture:** 28.72 Cu, 71.28 Sn.—**Analysis:** 25.12 Cu, 74.51 Sn.—**Dimensions:** Length, 6″. Diameter, 0.798″.

Broke at 750 pounds at D end.	Tenacity per square inch, 1,500 pounds.

RECORD OF TESTS BY TENSILE STRESS—Continued.

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TABLE LXXXIX.—ALLOY OF COPPER AND TIN.

Original mark: No. 21 A.—**Material:** Alloy.—**Original mixture:** 24.38 Cu, 75.62 Sn.—**Analysis:** 22.80 Cu, 76.89 Sn.—**Dimensions:** Rectangular section, 0.997″ x 1.007″.

Bar No. 21 contained a blowhole which extended throughout nearly its whole length. The tension-pieces were therefore left of the original rectangular section.

21 A broke at 6,300 pounds 1½ inches from C end.

Elongation, 0.01 inch in 6 inches.

Tenacity per square inch of *total* original section, 6,275 pounds.

The blowhole at the fractured surface was elliptical in section, measuring 0.21 x 0.18 inch in diameter.

The distances of the edges of the hole from the two nearest edges of the fractured surface were 0.27 and 0.36 inch. Area of blowhole, 0.0297 inch.

Tenacity per square inch of metal actually fractured, 6,493 pounds.

TABLE XC.—ALLOY OF COPPER AND TIN.

Original mark: No. 21 B.—**Material:** Alloy.—**Original mixture:** 24.38 Cu, 75.62 Sn.—**Analysis:** 23.89 Cu, 75.68 Sn.—**Dimensions:** Rectangular section, 1.000″ x 1.020″.

Broke at 7,420 pounds 3 inches from B end.

No elongation. Size of blowhole, 0.30 x 0.21 inch, elliptical. Area, 0.0495 inch. Position of blowhole, 0.25 inch and 0.30 inch from nearest edges.

Tenacity per square inch of metal actually fractured, 7,646 pounds.

Tenacity per square inch of total original section, 7,275 pounds.

TABLE XCI.—ALLOY OF COPPER AND TIN.

Original mark: No. 22 A.—**Material:** Alloy.—**Original mixture:** 21.18 Cu, 78.82 Sn.—**Analysis:** 20.28 Cu, 79.63 Sn.—**Dimensions:** Length, 6″. Diameter, 0.798″.

Broke at 3,220 pounds at A end.

No elongation detected.

Tenacity per square inch, 6,440 pounds.

TABLE XCII.—ALLOY OF COPPER AND TIN.

Original mark: No. 22 B.—**Material:** Alloy.—**Original mixture:** 21.18 Cu, 78.82 Sn.—**Analysis:** 20.21 Cu, 79.62 Sn.—**Dimensions:** Length, 6″. Diameter, 0.799″.

Broke at 1,120 pounds ½ inch from D end.

No elongation detected.

Tenacity per square inch, 2,234 pounds.

TABLE XCIII.—ALLOY OF COPPER AND TIN.

Original mark: No. 23 A.—**Material:** Alloy.—**Original mixture:** 15.19 Cu, 84.81 Sn.—**Analysis:** 15.12 Cu, 84.58 Sn.—**Dimensions:** Length, 6″. Diameter, 0.798″.

Broke at 275 pounds ½ inch from C end.

No elongation.

Tenacity per square inch, 550 pounds.

TABLE XCIV.—ALLOY OF COPPER AND TIN.

Original mark: No. 23 B.—**Material:** Alloy.—**Original mixture:** 15.19 Cu, 84.81 Sn.—**Analysis:** 15.04 Cu, 84.65 Sn.—**Dimensions:** Length, 6″. Diameter, 0.798″.

Load	Load per square inch.	Elongation in 5 inches.	Elongation in parts of original length.
Pounds.	*Pounds.*	*Inches.*	
2,700	5,400	0.01	.002
3,260	6,520	0.02	.004

Broke at D end.

Diameter of fractured section, 0.798 inch.

Tenacity per square inch original section, 6,520 pounds.

RECORD OF TESTS BY TENSILE STRESS—Continued

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TABLE XCV.—ALLOY OF COPPER AND TIN.

Original mark: No. 24 A.—**Material:** Alloy.—**Original mixture:** 11.84 Cu, 88.16 Sn.—**Analysis:** 11.49 Cu, 88.44 Sn.—**Dimensions:** Length, 6″. Diameter, 0.798″.

Load.	Load per square inch.	Elongation in 5 inches.	Elongation in parts of original length.
Pounds.	*Pounds.*	*Inches.*	
1, 650	3, 300	0. 01	. 0020
2, 760	5, 520	0. 04	. 0080
3, 260	6, 520	0. 06	. 0120
3, 300	6, 600	0. 10	. 0200
0	....	Set 0. 10	....
3, 300	6, 600	0. 13	. 0260
In 2 m.	6, 600	0. 37	. 0740

Broke 2 inches from A end.

Fractured section elliptical; diameters, 0.768 and 0.776 inch.

Tenacity per square inch original section, 6,600 pounds.

Tenacity per square inch fractured section, 7,050 pounds.

TABLE XCVI.—ALLOY OF COPPER AND TIN.

Original mark: No. 24 B.—**Material:** Alloy.—**Original mixture:** 11.84 Cu, 88.16 Sn.—**Analysis:** 11.48 Cu, 88.50 Sn.—**Dimensions:** Length, 6″. Diameter, 0.798″.

Load.	Load per square inch.	Elongation in 5.02 inches.	Elongation in parts of original length.
Pounds.	*Pounds.*	*Inches.*	
1, 820	3, 640	0. 01	. 002
2, 680	5, 360	0. 02	. 004
3, 080	6, 160	0. 04	. 008

Broke ¾ inch from B end.

Diameter of fractured section, 0.795 inch.

Tenacity per square inch original section, 6,160 pounds.

Tenacity per square inch fractured section, 6,204 pounds.

TABLE XCVII.—ALLOY OF COPPER AND TIN.

Original mark: No. 25 A.—**Material:** Alloy.—**Original mixture:** 9.7 Cu, 90.3 Sn.—**Analysis:** 8.82 Cu, 91.12 Sn.—**Dimensions:** Length, 6″. Diameter, 0.798″.

Load.	Load per square inch.	Elongation in 6.02 inches.	Elongation in parts of original length.
Pounds.	*Pounds.*	*Inches.*	
1, 520	3, 040	0. 01	. 0017
2, 200	4, 400	0. 02	. 0033
2, 520	5, 040	0. 04	. 0067
2, 830	5, 660	0. 07	. 0117
3, 000	6, 000	0. 11	. 0184
In 2 m.	6, 000	0. 43	. 0714

Broke 2⅛ inches from C end.

Diameter of fractured section, 0.730 inch.

Tenacity per square inch original section, 6,000 pounds.

Tenacity per square inch fractured section, 7,167 pounds.

TABLE XCVIII.—ALLOY OF COPPER AND TIN.

Original mark: No. 25 B.—**Material:** Alloy.—**Analysis:** 8.32 Cu, 91.66 Sn.—**Dimensions:** Length, 6″. Diameter, 0.798″.

Load.	Load per square inch.	Elongation in 5 inches.	Elongation in parts of original length.
Pounds.	*Pounds.*	*Inches.*	
2, 000	4, 000	0. 01	. 0020
2, 700	5, 400	0. 03	. 0060
2, 910	5, 820	0. 05	. 0100
3, 450	6, 900	0. 12	. 0240
In 1 m.	6, 900	0. 33	. 0660

Broke 1 inch from D end.

Diameter of fractured section, 0.740 inch.

Tenacity per square inch original section, 6,900 pounds.

Tenacity per square inch fractured section, 8,021 pounds.

RECORD OF TESTS BY TENSILE STRESS—Continued.

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TABLE XCIX.—ALLOY OF COPPER AND TIN.

Original mark: No. 26 A.—**Material:** Alloy.—**Original mixture:** 4.29 Cu, 95.71 Sn.—**Analysis:** 3.70 Cu, 96.30 Sn.—**Dimensions:** Length, 6″. Diameter, 0.798″.

Load.	Load per square inch.	Elongation in 6 inches.	Elongation in parts of original length.
Pounds.	*Pounds.*	*Inches.*	
1,300	2,600	0.01	.0017
1,530	3,060	0.04	.0067
1,850	3,700	0.10	.0167
2,000	4,000	0.16	.0267
2,150	4,300	0.19	.0333
In 2 m.	4,300	0.59	.0983

Broke in middle.
Diameter of fractured section, 0.680 inch.
Blow-hole 0.25 inch diameter in fractured surface.
Tenacity per square inch original section, 4,300 pounds.
Tenacity per square inch, deducting blowholes, 4,767 pounds.
Tenacity per square inch fractured section, 5,920 pounds.

TABLE C.—ALLOY OF COPPER AND TIN.

Original mark: No. 26 B.—**Material:** Alloy.—**Analysis:** 3.74 Cu, 96.32 Sn.—**Dimensions:** Length, 6″. Diameter, 0.798″.

Load.	Load per square inch.	Elongation in 5 inches.	Elongation in parts of original length.
Pounds.	*Pounds.*	*Inches.*	
1,550	3,100	0.01	.002
2,000	4,000	0.03	.006
2,630	5,260	0.09	.018
In 1 m.	5,260	0.62	.124
Reduced to—			
1,800	3,600	0.64	.128
In 2 m.	3,600	0.65	.030
In 4 m.	3,600	0.74	.148

Broke in middle.
Diameter of fractured section, 0.660 inch.
Breaking load, 2,630 pounds.
Tenacity per square inch original section, 5,260 pounds.
Tenacity per square inch fractured section, 7,687 pounds (assuming that the final section sustained the maximum load of 2,630 pounds).

TABLE CI.—ALLOY OF COPPER AND TIN.

Original mark: No. 27 A.—**Material:** Alloy.—**Original mixture:** 1.11 Cu, 98.80 Sn.—**Analysis:** 0.75 Cu, 98.89 Sn.—**Dimensions:** Length 6″. Diameter, 0.798″.

Load.	Load per square inch.	Elongation in 5.01 inches.	Elongation in parts of original length.
Pounds.	*Pounds.*	*Inches.*	
1,600	3,200	0.09	.018
In 1 m.	3,200	0.18	.036
1,800	3,600	0.24	.048
In 2 m.	3,600	0.40	.080
In 5 m.	3,600	0.65	.013
In 7 m.	3,600	1.26	.252
In 8 m.	3,600	1.58	.316

Broke in middle.
Diameter of fractured section, 0.550 inch.
Surface very much corrugated by strain.
Tenacity per square inch original section, 3,600 pounds.
Tenacity per square inch fractured section (assuming that the final section sustained the load of 1,800 pounds), 7,576 pounds.

TABLE CII.—ALLOY OF COPPER AND TIN.

Original mark: No. 27 B.—**Material:** Alloy.—**Original mixture:** 1.11 Cu, 98.89 Sn.—**Analysis,** 0.72 Cu, 99.06 Sn.—**Dimensions:** Length, 6″. Diameter, 0.798″.

Load.	Load per square inch.	Elongation in 5.08 inches.	Elongation in parts of original length.
Pounds.	*Pounds.*	*Inches.*	
1,550	3,100	0.13	.0224
In 2 m.	3,100	0.17	.0293
1,850	3,700	0.28	.0483
In 3 m.	3,700	0.72	.1241
0	....	Set 0.72	....
1,850	3,700	0.81	.1397

Broke 2 inches from B end.
Diameter of fractured section, 0.540 inch.
Tenacity per square inch original section, 3,700 pounds.
Tenacity per square inch fractured section, 8,157 pounds. (?)

RECORD OF TESTS BY TENSILE STRESS—Continued.

[*First series.*]

MECHANICAL LABORATORY, DEPARTMENT OF ENGINEERING, STEVENS INSTITUTE OF TECHNOLOGY.

TABLE CIII.—ALLOY OF COPPER AND TIN.

Original mark: No. 28 A.—**Material:** Alloy.—**Original mixture:** 0.557 Cu, 99.443 Sn.—**Analysis:** 0.32 Cu, 99.46 Sn.—**Dimensions:** Length, 6″. Diameter, 0.798″.

Load.	Load per square inch.	Elongation in 5 inches.	Elongation in parts of original length.	
Pounds.	*Pounds.*	*Inches.*		Broke in middle; greatest stress, 2,350 pounds. Diameter of fractured section, 0.455 inch. Surface very much distorted. Tenacity per square inch original section, 4,700 pounds. Tenacity per square inch fractured section (assuming that the final section sustained the maximum load of 2,350 pounds; plainly an error in this case), 14,453 pounds.
1, 400	2, 800	0. 02	. 004	
1, 700	3, 400	0. 05	. 0083	
1, 880	3, 760	0. 25	. 05	
2, 350	4, 700	Extending rapidly; measurement not taken.		
Reduced to—				
2, 200	4, 400	1. 80	. 36	

TABLE CIV.—ALLOY OF COPPER AND TIN.

Original mark: No. 28 B.—**Material:** Alloy.—**Original mixture:** 0.557 Cu, 99.443 Sn.—**Analysis:** 0.32 Cu, 99.4 Sn.—**Dimensions:** Length, 6″. Diameter, 0.798″.

Load.	Load per square inch.	Elongation in 6.02 inches.	Elongation in parts of original length.	
Pounds.	*Pounds.*	*Inches.*		Broke in middle. Diameter of fractured section, 0.475 inch. Tenacity per square inch original section, 4,250 pounds. Tenacity per square inch fractured section (assuming that the final section sustained the load of 2,125 pounds), 11,992 pounds.
1, 250	2, 500	0. 01	. 0017	
In 3 m.	2, 500	0. 03	. 0050	
1, 500	3, 000	0. 08	. 0133	
In 3 m.	3, 000	0. 30	. 0498	
In 8 m.	3, 000	0. 50	. 0831	
Increased strain rapidly to—				
2, 125	4, 250	1. 93	. 3206	
Reduced to—				
1, 400	2, 800	2. 10	. 3488	

TABLE CV.—CAST TIN.

Original mark: No. 29 A.—**Material:** Banca tin.—**Dimensions:** Length, 6″. Diameter, 0.798″.

Load.	Load per square inch.	Elongation in 6 inches.	Elongation in parts of original length.	
Pounds.	*Pounds.*	*Inches.*		Broke ½ inch from A end. Diameter of fractured section, 0.490 inch (approximately). The section was very much distorted, and an exact measurement could not be obtained. Tenacity per square inch of original section, considering 1,400 pounds as the breaking load, 2,800 pounds (with gradual test).
1, 700	3, 400	0. 15	. 025	
0	....	Set 0. 15	. 025	
Reduced to—				
1, 250	2, 500	0. 19	. 0318	
In 2 m.	2, 500	0. 27	. 045	
1, 400	2, 800	0. 32	. 0533	
In 10 m.	2, 800	1. 70	. 2833	

RECORD OF TESTS BY TENSILE STRESS—Continued.

[*First series.*]

MECHANICAL LABORATORY, DEPARTMENT OF ENGINEERING, STEVENS INSTITUTE OF TECHNOLOGY.

TABLE CVI.—CAST TIN.

Original mark: No. 29 B.—Material: Banca tin.—Dimensions: Length, 6″. Diameter, 0.798″.

Load.	Load per square inch.	Elongation in 6.02 inches.	Elongation in parts of original length.
Pounds.	*Pounds.*	*Inches.*	
975	1,950	0.01	.0017
1,180	2,360	0.03	.0050
1,290	2,580	0.09	.0150
1,600	3,200	0.20	.0332
2,000	4,000	0.58	.0963
2,100	4,200	1.88	.3123
Piece extending rapidly and strain reduced to—			
1,700	3,400	2.58	.4269

Broke 2 inches from D end.

Fractured section very irregular, and drawn out almost to a point. Estimated diameter of final section 0.300 inch.

Tenacity per square inch of original section (*with rapid test*) 4,200 pounds.

TABLE CVII.—CAST COPPER.

Original mark: No. 30 A.—Material: Lake Superior copper, cast in iron mold.—Dimensions: Length, 5″. Diameter, 0.798″.

Load.	Load per square inch.	Elongation in 5 inches.	Elongation in parts of original length.
Pounds.	*Pounds.*	*Inches.*	
400	800	0.0004	.00008
1,000	2,000	0.0011	.00022
2,000	4,000	0.0022	.00044
4,000	8,000	0.0027	.00054
6,000	12,000	0.0032	.00064
6,400	12,800	0.0052	.00104
6,800	13,600	0.0083	.00166
7,200	14,400	0.0132	.00264
8,000	16,000	0.0358	.00716
8,800	17,600	0.0642	.01284
9,600	19,200	0.0942	.01884
9,800	19,600	0.1073	.02146
250	500	Set 0.0951	....
10,200	20,400	0.1218	.02436
11,000	22,000	0.1605	.03210
12,200	24,400	0.2191	.04382
14,000	28,000	0.3258	.06516
270	540	Set 0.3155	....
14,400	28,800	0.3448	.06896
14,600	29,200	0.3760	.07520

Broke just as reading was taken ¼ inch from A end. Fractured section distorted from circular form. Three diameters measured 0.737 inch, 0.725 inch, and 0.732 inch.

Tenacity per square inch original section, 29,200 pounds.

Tenacity per square inch fractured section, 34,790 pounds.

TABLE CVIII.—CAST COPPER.

Original mark: No. 30 B.—Material: Cast copper.—Dimensions: Length, 5″. Diameter, 0.798″.

Load.	Load per square inch.	Elongation in 5 inches.	Compression in parts of original length.
Pounds.	*Pounds.*	*Inches.*	
6,400	12,800	0.0035	.00070
7,000	14,000	0.0081	.00162
7,200	14,400	0.0111	.00222
7,800	15,600	0.0259	.00518
8,400	16,800	0.0439	.00878
9,000	18,000	0.0652	.01304
9,400	18,800	0.0807	.01614
9,800	19,600	0.0952	.01904
10,200	20,400	0.1147	.02294
10,600	21,200	0.1317	.02634
11,000	22,000	0.1517	.03034
11,400	22,800	0.1707	.03414
11,800	23,600	0.1967	.03934
12,200	24,400	0.2182	.04364
12,600	25,200	0.2437	.04874
13,000	26,000	0.2707	.05414
13,200	26,400	....	....

Broke in middle just as beam rose.

Fractured section elliptical. Diameters, 0.752 and 0.740 inch.

Tenacity per square inch original section, 26,400 pounds.

Tenacity per square inch fractured section, 30,201 pounds.

NOTE.—The piece bent slightly under strains less than 6,400 pounds, and thus caused errors in the readings of elongations below that point.

RECORD OF TESTS BY COMPRESSIVE STRESS.

MECHANICAL LABORATORY, DEPARTMENT OF ENGINEERING, STEVENS INSTITUTE OF TECHNOLOGY.

TABLE CIX.—CAST COPPER.

Original mark: No. 1.—**Material:** Lake Superior copper.—**Dimensions:** Length, 2″. Diameter, 0.625″.

Load.	Compression.	Load per square inch.	Compression in parts of original length.
Pounds.	*Inches.*	*Pounds.*	
1,000	0.0029	3,259	.00145
1,500	0.0087	4,889	.00435
2,000	0.015	6,519	.0075
3,000	0.022	9,778	.0110
4,000	0.030	13,038	.0150
5,000	0.043	16,297	.0215
6,000	0.065	19,557	.0325
7,000	0.079	22,816	.0395
8,000	0.097	26,076	.0485
9,000	0.128	29,335	.0640
10,000	0.153	32,595	.0765
11,000	0.182	35,854	.0910
12,000	0.209	39,114	.1045
13,000	0.251	42,373	.1255
14,000	0.304	45,633	.1520
15,000	0.368	48,892	.1840
16,250	0.426	52,967	.2130
17,000	0.477	55,411	.2385
18,000	0.528	58,671	.2640
18,925	0.584	61,688	.2920
19,600	0.633	63,886	.3165
20,500	0.707	66,820	.3535
22,000	0.838	71,709	.4190
23,000	0.896	74,968	.4480

Piece removed bent.

Piece slightly bent at 9,000 pounds. After 17,000 pounds the beam dropped immediately after the strain was applied.

TABLE CX.—CAST COPPER.

Original mark: No. 1 D.—**Material:** Cast copper.—**Dimensions:** Length, 2″. Diameter, 0.625″.

150	.0000	....	....
4,000	.0025	13,038	.00125
6,000	.0233	19,557	.0116
8,000	.0538	26,075	.0269
10,000	.0908	32,595	.0454
12,000	.1271	39,114	.0635
14,000	.2073	45,633	.1036
16,000	.2924	52,152	.1462
18,000	.4115	58,671	.2057
20,000	.5249	65,188	.2624
22,000	.7018	71,709	.3509
24,000	.8678	78,228	.4339
25,000	....	....	....

Lifted the beam.

TABLE CXI.—ALLOY OF COPPER AND TIN.

Original mark: No. 2 D.—**Material:** Alloy.—Original mixture: 98.1 Cu, 1.9 Sn.—Analysis 97.83 Cu, 1.92 Sn.—**Dimensions:** Length, 2″. Diameter, 0.625″.

500	0.005	1,630	.0025
1,000	0.009	3,259	.0045
2,000	0.015	6,519	.0075
3,000	0.021	9,778	.0105
4,000	0.026	13,038	.0130
5,000	0.028	16,297	.0140
6,000	0.032	19,557	.0160
7,000	0.038	22,816	.0190
8,000	0.047	26,076	.0235
9,000	0.074	29,335	.0370
Repeated.			
9,000	0.106	29,335	.0530
10,000	0.170	32,595	.0850
11,000	0.225	35,854	.1125
12,000	0.267	39,114	.1335
13,000	0.327	42,373	.1635
14,000	0.386	45,633	.1930
14,500	0.480	46,263	.2400
Reduced to—			
14,000	0.538	45,633	.2690
13,000	0.590	42,373	.2950
10,000	0.639	32,595	.3195
7,000	0.685	22,816	.3425
2,000	0.736	6,519	.3680

Piece removed bent so that it rested on two corners only.

The bending of the piece was first observed at 9,000 pounds.

RECORD OF TESTS BY COMPRESSIVE STRESS—Continued.

MECHANICAL LABORATORY, DEPARTMENT OF ENGINEERING, STEVENS INSTITUTE OF TECHNOLOGY.

TABLE CXII.—ALLOY OF COPPER AND TIN.

Original mark: No. 3 D.—**Material:** Alloy.—**Original mixture:** 96.27 Cu, 3.73 Sn.—**Analysis:** 95.96 Cu, 3.80 Sn.—**Dimensions:** Length, 2″. Diameter, 0.625″.

Load.	Compression.	Load per square inch.	Compression in parts of original length.	Load.	Compression.	Load per square inch.	Compression in parts of original length.
Pounds.	*Inches.*	*Pounds.*		*Pounds.*	*Inches.*	*Pounds.*	
500	0.003	1,630	.0015	Reduced to—			
2,000	0.010	6,519	.0050	11,900	0.192	38,788	.0960
3,000	0.014	9,778	.0070	12,300	0.255	40,092	.1275
4,000	0.020	13,038	.0100	13,000	0.269	42,373	.1345
5,000	0.022	16,297	.0110	14,000	0.289	45,633	.1445
6,000	0.025	19,557	.0125	15,000	0.313	48,892	.1560
7,000	0.027	22,816	.0135	15,600	0.346	50,848	.1730
8,000	0.030	26,076	.0150	16,000	0.372	52,152	.1860
9,000	0.033	29,335	.0165	Reduced to—			
10,000	0.041	32,595	.0205	14,800	0.390	48,241	.1950
11,000	0.053	35,854	.0265	10,000	0.539	32,595	.2695
11,500	0.069	37,484	.0345	2,000	0.605	6,519	.3025
12,000	0.093	39,114	.0465				
12,500	0.135	40,744	.0675				
12,900	0.160	42,048	.0800				

Piece removed bent in a double curve.
Bending first observed at 12,500 pounds.

TABLE CXIII.—ALLOY OF COPPER AND TIN.

Original mark: No. 4 B.—**Material:** Alloy.—**Original mixture:** 92.8 Cu, 7.2 Sn.—**Dimensions:** Length, 2″. Diameter, 0.625″.

Load.	Compression.	Load per square inch.	Compression in parts of original length.	Load.	Compression.	Load per square inch.	Compression in parts of original length.
500	0.005	1,630	.0025	16,000	0.287	52,152	.1435
1,000	0.010	3,259	.0050	17,500	0.332	57,041	.1660
2,000	0.015	6,519	.0075	19,000	0.370	61,930	.1850
3,000	0.020	9,778	.0100	21,000	0.429	68,449	.2145
4,000	0.024	13,038	.0120	23,000	0.489	74,968	.2445
5,000	0.028	16,297	.0140	25,000	0.537	81,487	.2685
6,000	0.031	19,557	.0155	25,800	0.581	84,095	.2905
7,000	0.037	22,816	.0175	Strain decreased in 1 min. to—			
8,000	0.044	26,076	.0220	25,000	0.702	81,487	.3510
9,000	0.062	29,335	.0310	20,000	0.820	65,190	.4100
9,500	0.080	30,965	.0400	14,000	0.870	45,633	.4350
10,000	0.120	32,595	.0600	2,500	0.907	24,446	.4535
11,000	0.140	35,854	.0700				
12,000	0.159	39,114	.0795				
14,000	0.225	45,633	.1125				

Piece removed bent.
Bending first observed at 9,000 pounds.

TABLE CXIV.—ALLOY OF COPPER AND TIN.

Original mark: No. 5 D.—**Material:** Alloy.—**Original mixture:** 90 Cu, 10 Sn.—**Analysis:** 90.43 Cu, 9.50 Sn.—**Dimensions:** Length, 2″. Diameter, 0.625″.

Load.	Compression.	Load per square inch.	Compression in parts of original length.	Load.	Compression.	Load per square inch.	Compression in parts of original length.
500	0.007	1,630	.0035	15,600	0.302	50,848	.1510
1,000	0.010	3,259	.0050	17,000	0.333	55,411	.1675
2,000	0.016	6,519	.0080	18,000	0.366	58,671	.1830
3,000	0.022	9,778	.0110	19,000	0.442	61,930	.2210
4,000	0.026	13,038	.0130	Reduced to—			
5,000	0.030	16,297	.0150	18,800	0.469	61,279	.2345
6,000	0.034	19,557	.0170	18,000	0.546	58,671	.2730
7,000	0.044	22,816	.0220	16,300	0.579	53,130	.2895
8,000	0.059	26,076	.0295	14,500	0.604	47,263	.3020
9,000	0.080	29,335	.0400	10,600	0.635	34,551	.3175
10,000	0.110	32,595	.0550	4,000	0.671	13,038	.3355
11,000	0.154	35,854	.0770				
12,250	0.231	39,929	.1155				
13,500	0.244	44,003	.1220				
14,500	0.266	47,263	.1330				

Piece bent and slipped out from between the pressure-plates.
Bending first observed at 10,000 pounds.

RECORD OF TESTS BY COMPRESSIVE STRESS—Continued.

MECHANICAL LABORATORY, DEPARTMENT OF ENGINEERING, STEVENS INSTITUTE OF TECHNOLOGY.

TABLE CXV.—ALLOY OF COPPER AND TIN.

Original mark: No. 6 B.—**Material:** Alloy.—**Original mixture:** 86.57 Cu, 13.43 Sn.—**Analysis,** 87.15 Cu, 12.77 Sn.—**Dimensions:** Length, 2″. Diameter, 0.625″.

Load.	Compression.	Load per square inch.	Compression in parts of original length.	Load.	Compression.	Load per square inch.	Compression in parts of original length.
Pounds.	*Inches.*	*Pounds.*		*Pounds.*	*Inches.*	*Pounds.*	
1,000	0.005	3,259	.0025	22,000	0.337	71,709	.1685
2,000	0.011	6,519	.0055	24,000	0.390	78,228	.1950
4,000	0.018	13,038	.0090	26,000	0.449	84,747	.2245
6,000	0.023	19,557	.0115	27,500	0.496	89,636	.2480
8,000	0.028	26,076	.0140	Decreased to—			
10,000	0.045	32,595	.0225	27,250	0.531	88,821	.2655
11,000	0.066	35,854	.0330	26,100	0.599	85,073	.2995
12,000	0.101	39,114	.0505	24,000	0.665	78,228	.3325
14,000	0.146	45,633	.0730	20,000	0.716	65,190	.3580
16,000	0.197	52,152	.0985	17,000	0.741	55,411	.3705
17,000	0.218	55,411	.1090	10,000	0.772	32,595	.3860
18,000	0.244	58,671	.1220	Piece slipped out from between pressure-plates.			
20,500	0.298	66,820	.1490	Bending first observed at 11,000 pounds.			

TABLE CXVI.—ALLOY OF COPPER AND TIN.

Original mark: No. 7 A.—**Material:** Alloy.—**Original mixture:** 80 Cu, 20 Sn.—**Analysis:** 80.99 Cu, 18.92 Sn.—**Dimensions:** Length, 2″. Diameter, 0.625″.

500	0.006	1,630	.0030	24,000	0.202	78,228	.1010
1,000	0.012	3,259	.0060	26,000	0.215	84,747	.1075
2,000	0.015	6,519	.0075	28,000	0.241	91,266	.1205
3,000	0.020	9,778	.0100	30,000	0.285	97,785	.1425
4,000	0.023	13,038	.0115	31,000	0.298	101,044	.1490
6,000	0.031	10,557	.0155	31,750	0.328	103,489	.1640
8,000	0.038	26,076	.0190	Decreased to—			
10,000	0.044	32,595	.0220	30,600	0.354	99,741	.1770
12,000	0.052	39,114	.0260	29,000	0.390	94,525	.1950
14,000	0.059	45,633	.0295	28,000	0.406	91,266	.2030
16,000	0.069	52,152	.0345	Piece flew out from between pressure-plates, a small piece breaking from one corner.			
18,000	0.082	58,671	.0410	Bending first observed at 20,500 pounds.			
20,000	0.106	65,190	.0530				
22,000	0.187	71,709	.0935				

TABLE CXVII.—ALLOY OF COPPER AND TIN.

Original mark: No. 8 B.—**Material:** Alloy.—**Original mixture:** 76.32 Cu, 23.68 Sn.—**Analysis:** 76.60 Cu, 23.23 Sn.—**Dimensions:** Length, 2″. Diameter, 0.625″.

1,000	0.003	3,259	.0015	28,000	0.078	91,266	.0390
2,000	0.011	6,519	.0055	30,000	0.090	97,785	.0450
3,000	0.015	9,778	.0075	31,000	0.100	101,044	.0500
4,000	0.020	13,038	.0100	32,000	0.110	104,303	.0550
6,000	0.027	19,557	.0135	33,000	0.132	107,562	.0660
8,000	0.033	26,076	.0165	Reduced to—			
10,000	0.036	32,595	.0180	31,200	0.158	101,696	.0790
12,000	0.039	39,114	.0195	32,000	0.171	104,303	.0855
14,000	0.042	45,633	.0210	33,000	0.173	107,562	.0865
16,000	0.046	52,152	.0230	34,000	0.175	110,822	.0875
18,000	0.050	58,671	.0250	35,000	0.181	114,081	.0105
20,000	0.058	65,190	.0290	Piece broke suddenly diagonally across the middle. One piece flew out from the machine to a distance of 12 feet.			
22,000	0.059	71,709	.0295				
24,000	0.065	78,228	.0325				
26,000	0.073	84,747	.0365				

RECORD OF TESTS BY COMPRESSIVE STRESS—Continued.

MECHANICAL LABORATORY, DEPARTMENT OF ENGINEERING, STEVENS INSTITUTE OF TECHNOLOGY.

TABLE CXVIII.—ALLOY OF COPPER AND TIN.

Original mark: No. 9.—Material: Alloy.—Original mixture: 70 Cu, 30 Sn.—Analysis: 69.90 Cu, 29.85 Sn.—Dimensions: Length, 2″. Diameter, 0.625″.

Load.	Compression.	Load per square inch.	Compression in parts of original length.	Load.	Compression.	Load per square inch.	Compression in parts of original length.
Pounds.	*Inches.*	*Pounds.*		*Pounds.*	*Inches.*	*Pounds.*	
1,000	0.001	3,259	.0005	30,000	0.055	97,785	.0275
2,000	0.008	6,519	.0040	32,000	0.056	104,303	.0280
4,000	0.017	13,038	.0085	34,000	0.058	110,822	.0290
8,000	0.031	26,076	.0155	36,000	0.059	117,341	.0295
10,000	0.038	32,595	.0190	38,000	0.060	123,860	.0300
12,000	0.039	39,114	.0195	40,000	0.063	130,379	.0315
14,000	0.043	45,633	.0215	45,000	0.065	136,898	.0325
16,000	0.045	52,152	.0225	44,000	0.068	143,417	.0340
18,000	0.046	58,671	.0230	45,000	0.070	146,676	.0350
20,000	0.049	65,190	.0245				
22,000	0.050	71,709	.0250				
24,000	0.052	78,228	.0260				
26,000	0.053	84,747	.0265				
28,000	0.054	91,266	.0270				

About 30 seconds after the strain was applied the piece broke suddenly with a loud report, and flew into small pieces. The largest piece that could be found was about the size of a pea.

TABLE CXIX.—ALLOY OF COPPER AND TIN.

Original mark: No. 11.—Material: Alloy.—Original mixture: 65 Cu, 35 Sn.—Analysis: 65.31 Cu, 34.47 Sn.—Dimensions: Length, 2″. Diameter, 0.625″.

2,000	0.006	6,519	.0030	18,000	0.043	58,671	.0215
3,000	0.011	9,778	.0055	20,000	0.046	65,190	.6230
4,000	0.020	13,038	.0100	22,000	0.048	71,709	.0240
6,000	0.023	19,557	.0115	24,000	0.051	78,228	.0255
8,000	0.025	26,076	.0125	25,000	0.052	81,487	.0260
10,000	0.030	32,595	.0150	26,000	0.057	84,747	.0285
12,000	0.034	39,114	.0170				
14,000	0.038	45,633	.0190				
16,000	0.041	52,152	.0205				

Piece broke suddenly, several pieces flying off upper end.

TABLE CXX.—ALLOY OF COPPER AND TIN.

Original mark: No. 12.—Material: Alloy.—Original mixture: 61.71 Cu, 38.29 Sn.—Analysis: 6.—Dimensions: Length, 2″. Diameter, 0.625″.

2,000	0.004	6,519	.0020	9,000	0.031	29,335	.0155
3,000	0.010	9,778	.0030	10,000	0.032	32,595	.0100
4,000	0.014	13,038	.0070	11,000	0.033	35,854	.0165
5,000	0.018	16,297	.0090	12,000	0.035	39,114	.0175
6,000	0.021	19,557	.0105				
7,000	0.024	22,816	.0120				
8,000	0.027	26,076	.0135				

Broke suddenly, splitting open the upper end, with a wedge-shaped piece left in the middle.

TABLE CXXI.—ALLOY OF COPPER AND TIN.

Original mark: No. 15.—Material: Alloy.—Original mixture: 47.95 Cu, 52.05 Sn.—Analysis: 47.72 Cu, 51.99 Sn.—Dimensions: Length, 2″. Diameter, 0.625″.

1,500	0.002	4,889	.0010	12,000	0.030	39,114	.0150
2,500	0.006	8,149	.0030	14,000	0.031	45,633	.0155
3,500	0.011	11,408	.0055	16,000	0.034	52,152	.0170
4,500	0.015	14,668	.0075	18,000	0.036	58,671	.0180
5,500	0.017	17,927	.0085	20,000	0.040	65,190	.0200
6,500	0.018	21,187	.0090	21,000	0.041	68,449	.0205
7,500	0.021	24,446	.0105	25,000	0.043	81,487	.0215
8,500	0.025	27,706	.0125	26,000	0.043	84,747	....
9,500	0.027	30,965	.0135				
10,500	0.029	34,225	.0145				

Broke in applying strain.

RECORD OF TESTS BY COMPRESSIVE STRESS—Continued.

MECHANICAL LABORATORY, DEPARTMENT OF ENGINEERING, STEVENS INSTITUTE OF TECHNOLOGY.

TABLE CXXII.—ALLOY OF COPPER AND TIN.

Original mark: No. 16 B.—Material: Alloy.—Original mixture: 44.63 Cu, 55.37 Sn.—Analysis: 44.62 Cu, 55.15 Sn.—Dimensions: Length, 2″. Diameter, 0.625″.

Load.	Compression.	Load per square inch.	Compression in parts of original length.	Load.	Compression.	Load per square inch.	Compression in parts of original length.
Pounds.	*Inches.*	*Pounds.*		*Pounds.*	*Inches.*	*Pounds.*	
2,000	0.005	6,519	.0010	10,000	0.031	32,595	.006[illegible]
3,000	0.010	9,778	.0020	Repeated—			
4.000	0.014	13,038	.0028	10,000	0.033	32,595	.0066
5,000	0.018	16,297	.0036	11,000	....	35,854	....
6,000	0.022	19,557	.0044				
7.000	0.025	22,816	.0050				
8,000	0.027	26,076	.0054				
9,000	0.029	29,335	.0058				

Broke in applying strain, a cone-shaped wedge at the top of the piece apparently crushing out the metal on all sides of it.

TABLE CXXIII.—ALLOY OF COPPER AND TIN.

Original mark: No. 17 D.—Material: Alloy.—Original mixture: 41.74 Cu, 58.26 Sn.—Analysis: 38.83 Cu, 60.79 Sn.—Dimensions; Length, 2″. Diameter, 0.625.″

1,000	0.004	3,259	.0020	8,000	0.030	26,076	.0150
2,000	0.009	6,519	.0045	9,000	0.033	29,335	.0165
3,000	0.015	9,778	.0075	10,000	0.035	32,595	.0175
4,000	0.018	13,038	.0090	11,000	0.039	35,854	.0195
5,000	0.021	16,297	.0105	12,000	0.041	39,114	.0205
6,000	0.024	19,557	.0120				
7,000	0.026	22,816	.0130				

Broke just as strain was applied. Conical wedge-shaped fracture, like No. 16 B.

TABLE CXXIV.—ALLOY OF COPPER AND TIN.

Original mark: No. 17 B.—Material: Alloy.—Original mixture: 41.74 Cu, 58.26 Sn.—Analysis: 38.83 Cu, 60.79 Sn.—Dimensions: Length 2″. Diameter, 0.625″.

2,000	0.004	6,519	.0020	8,000	0.023	26,076	.0115
3,000	0.009	9,778	.0045	9,000	0.025	29,335	.0125
4,000	0.013	13,038	.0065	10,000	0.028	32,595	.0140
5,000	0.017	16,297	.0085	11,000	0.031	35,854	.0155
6,000	0.019	19,557	.0095	12,000	0.034	39,114	.0170
7,000	0.021	22,816	.0105				

Broke in applying strain. Fracture like 17 D.

TABLE CXXV.—ALLOY OF COPPER AND TIN.

Original mark: No. 18 D.—Material: Alloy.—Original mixture: 39.2 Cu, 60.8 Sn.—Analysis: 38.37 Cu, 61.32 Sn.—Dimensions: Length. 2″. Diameter, 0.625″.

1,000	0.003	3,259	.0015	7,000	0.027	22,816	.0135
2,000	0.009	6,519	.0045	8,000	0.029	26,076	.0145
3,000	0.014	9,778	.0070	9,000	....	29,335	....
4,000	0.019	13,038	.0095				
5,000	0.021	16,297	.0105				
6,000	0.024	19,557	.0120				

Broke in applying strain, pieces being crushed off upper end.

TABLE CXXVI.—ALLOY OF COPPER AND TIN.

Original mark: No. 19 B.—Material: Alloy.—Original mixture: 34.95 Cu, 65.05 Sn.—Analysis: 34.22 Cu, 65.80 Sn.—Dimensions: Length, 2″. Diameter, 0.625″.

1,000	0.002	3,519	.0010	4,850	0.051	15,809	.0255
2,000	0.006	6,519	.0030	3,200	0.066	10,430	.0330
3,000	0.011	9,778	.0055	2,300	0.096	7,497	.0480
4,000	0.016	13,038	.0080	2,700	0.111	8,801	.0555
5,000	0.020	16,297	.0100				
6,000	0.024	19,557	.0120				
Strain decreased to—							
4,100	0.044	13,364	.0220				

Piece bulged out in the middle. Bulging commenced at 6,000 pounds.

RECORD OF TESTS BY COMPRESSIVE STRESS—Continued.

MECHANICAL LABORATORY, DEPARTMENT OF ENGINEERING, STEVENS INSTITUTE OF TECHNOLOGY.

TABLE CXXVII.—ALLOY OF COPPER AND TIN.

Original mark: No. 20 B.—**Material:** Alloy.—**Original mixture:** 28.72 Cu, 71.28 Sn.—**Analysis:** 25.12 Cu, 74.51 Sn.—**Dimensions:** Length, 2″. Diameter, 0.625″.

Load.	Compression.	Load per square inch.	Compression in parts of original length.
Pounds.	*Inches.*	*Pounds.*	
1,500	0.004	4,889	.0020
2,000	0 010	6,519	.0050
3,000	0.018	9,778	.0090
4,000	0.023	13,038	.0115
5,000	0.029	16,297	.0145
5,500	0.034	17,927	.0170
Strain reduced to—			
4,450	0.062	14,505	.0310
2,700	0.077	8,801	.0385
1,700	0.088	5,541	.0440
900	0.136	2,934	.0680
1,000	0.168	3,259	.0840
1,500	0.194	4,889	.0970
2,000	0.243	6,519	.1215
2,500	0.331	8,149	.1655
3,000	0.458	9,778	.2290
3,150	0.512	10,267	.2560
3,000	0.561	9,778	.2805

Removed piece.

At 2,700 pounds (compression 0.077), after the piece had resisted 5,500 pounds, a wedge-shaped piece was observed to be cracked off at the upper corner, but not separated. At 2,000 pounds (compression 0.243) the wedge-shaped piece was crushed out to one side of the compression specimen.

Soon afterwards a second wedge-shaped piece was crushed off from the opposite upper corner, and when the test-piece was removed, after a compression of 0.561, both wedges still remained attached to it.

TABLE CXXVIII.—ALLOY OF COPPER AND TIN.

Original mark: No. 22 B.—**Material:** Alloy.—**Original mixture:** 21.18 Cu, 78.82 Sn.—**Analysis:** 20.21 Cu, 79.62 Sn.—**Dimensions:** Length, 2″. Diameter, 0.625″.

750	0.011	3,445	.0055
1,000	0.015	3,259	.0075
1,500	0.018	4,889	.0090
2,000	0.022	6,519	.0110
3,000	0.026	9,778	.0130
4,000	0.034	13,038	.0170
5,000	0.047	16,297	.0235
Strain decreased to—			
4,850	0.068	15,809	.0340
4,800	0.089	15,646	.0445
3,000	0.101	9,778	.0505
3,200	0.119	10,430	.0595
2,650	0.137	8,638	.0685
2,150	0.167	7,008	.0835
2,500	0.184	8,149	.0920
3,000	0.238	9,778	.1190
3,200	0.274	10,430	.1370
2,500	0.317	8,149	.1585
2,000	0.416	6,519	.0280
1,200	0.503	3,911	.2515
400	0.581	1,304	.2905

Piece slipped out from between the pressure-plates. Bent in a double curve with a crack on the convex side of each curve.

Double curve observed at 5,000 pounds. At 4,800 pounds (compression 0.089) the resistance decreased in 2 minutes to 3,300.

TABLE CXXIX.—ALLOY OF COPPER AND TIN.

Original mark: No. 23 A.—**Material:** Alloy.—**Original mixture:** 15.19 Cu, 84 81 Sn.—**Analysis:** 15.12 Cu, 84.58 Sn.—**Dimensions:** Length, 2″. Diameter, 0.625″.

750	0.008	2,445	.0040
1,000	0.012	3,259	.0060
1,500	0.015	4,889	.0075
2,000	0.030	6,519	.0150
2,000	0.112 0.200	6,519	.0560 .1300
In 5 minutes strain decreased to—			
1,600	0.338	5,215	.1690
1,400	0.417	4,563	.2085
1,500	0.500	4,889	.2500
1,700	0.609	5,541	.3045
2,000	0.706	6,519	.3530
2,600	0.793	8,475	.3965
2,800	0.914	9,127	.4570
2,900	1.027	9,452	.5135

Removed piece.

At 2,000 pounds (compression 0.112) the piece was slightly bulged out ⅛ inch from the bottom.

At 2,900 (compression 1.027) the wedge-shaped pieces separated from the remainder of the specimen.

TABLE CXXX.—ALLOY OF COPPER AND TIN.

Original mark: No. 24 B.—**Material:** Alloy.—**Original mixture:** 11.84 Cu, 88.16 Sn.—**Analysis:** 11.48 Cu, 88.50 Sn.—**Dimensions:** Length, 2″. Diameter, 0.625″.

500	0.012	1,630	.0060
1,000	0.020	3,259	.0100
2,000	0.032	6,519	.0160
3,000	0.059	9,778	.0295
3,100	0.139	10,104	.0695
3,000	0.174	9,778	.0870
3,400	0.509	11,082	.2995
3,900	0.857	12,712	.4285
4,300	1.008	14,016	.5040

Removed piece.

At 3,100 a slight double curve was observed.

At 3,400 the scale-beam dropped instantly if the motion of the handle was stopped, but rose on starting again.

When removed, the piece was slightly bent in a double curve and increased in diameter to about 0.85 inch.

RECORD OF TESTS BY COMPRESSIVE STRESS—Continued.

MECHANICAL LABORATORY, DEPARTMENT OF ENGINEERING, STEVENS INSTITUTE OF TECHNOLOGY.

TABLE CXXXI.—ALLOY OF COPPER AND TIN.

Original mark: No. 25 A.—**Material:** Alloy.—**Original mixture:** 9.70 Cu, 90.30 Sn.—**Analysis:** 8.57 Cu, 91.39 Sn.—**Dimensions:** Length, 2″. Diameter, 0.625″.

Load.	Compression.	Load per square inch.	Compression in parts of original length.	Load.	Compression.	Load per square inch.	Compression in parts of original length.
Pounds.	*Inches.*	*Pounds.*		*Pounds.*	*Inches.*	*Pounds.*	
150	.0000	....	....	3,000	Lifted the beam.		
1,000	.0009	3,259	.0004	Wedge-shaped pieces cracked at the top and botton of the specimen, but did not break off.			
2,000	.1117	6,519	.0558				

TABLE CXXXII.—ALLOY OF COPPER AND TIN.

Original mark: No. 26 B.—**Material:** Alloy.—**Original mixture:** 4.29 Cu, 95.71 Sn.—**Analysis:** 3.72 Cu, 96.31 Sn.—**Dimensions:** Length, 2″. Diameter, 0.625″.

150	.0000	....	....	2,000	.6845	6,519	.3422
1,000	.0007	3,259	.00035	3,000	Lifted the beam.		

TABLE CXXXIII.—ALLOY OF COPPER AND TIN.

Original mark: No. 27 D.—**Material:** Alloy.—**Original mixture:** 1.11 Cu, 98.89 Sn.—**Analysis:** 0.74 Cu, 99.02 Sn.—**Dimensions:** Length, 2″. Diameter, 0.625″.

150	.0000	....	....	2,000	.7264	6,519	.3632
1,000	.0073	3,359	.0036	3,000	....	....	....

TABLE CXXXIV.—ALLOY OF COPPER AND TIN.

Original mark: No. 28 C.—**Material:** Alloy.—**Original mixture:** 0.557 Cu, 99.443 Sn.—**Analysis:** 0.32 Cu, 99.46 Sn.—**Dimensions:** Length, 2″. Diameter, 0.625″.

150	.0000	....	....	3,000	Lifted the beam.		
1,000	.0038	3,259	.0019	Cracked through the middle, but did not separate.			
2,000	.7520	6,519	.3760				

TABLE CXXXV.—CAST TIN.

Original mark: No. 29 C.—**Material:** Banca tin, cast in iron mold.—**Dimensions:** Length, 2″. Diameter, 0.625″.

1,250	0.003	4,074	.0015	2,300	0.899	7,497	.4445
1,500	0.012	4,889	.0060				
1,750	0.043	5,704	.0215	Removed piece.			
1,850	0.097	6,030	.0485	At 1,850 pounds the piece was observed to be bulging out on all sides, but still remaining vertical. At the end of the test the piece had a slight bend in one direction, and was increased in diameter to 0.85 and 0.89 inch in different parts of the length.			
1,900	0.158	6,193	.0790				
2,000	0.265	6,519	.1325				
2,000	0.473	6,519	.2365				
2,200	0.612	7,171	.3060				
2,300	0.729	7,497	.3645				

RECORD OF TESTS BY COMPRESSIVE STRESS—Continued.

MECHANICAL LABORATORY, DEPARTMENT OF ENGINEERING, STEVENS INSTITUTE OF TECHNOLOGY.

CXXXVI.—CAST COPPER.

Original mark: No. 30.—**Material:** Lake Superior copper, cast in iron mold.—**Dimensions:** Length, 2″ Diameter, 0.625″.

Load.	Compression.	Load per square inch.	Compression in parts of original length.	Load.	Compression.	Load per square inch.	Compression in parts of original length.
Pounds.	*Inches.*	*Pounds.*		*Pounds.*	*Inches.*	*Pounds.*	
500	0. 003	1, 630	.0015	12, 000	0. 162	39, 114	.0810
1, 000	0. 005	3, 259	.0025	13, 000	0. 205	42, 373	.1025
2, 000	0. 008	6, 519	.0040	14, 000	0. 251	45, 633	.1255
3, 000	0. 011	9, 778	.0055	15, 000	0. 294	48, 892	.1470
4, 000	0. 014	13, 038	.0070	16, 000	0. 337	52, 152	.1685
5, 000	0. 018	16, 297	.0090	18, 000	0. 422	58, 671	.2110
6, 000	0. 021	19, 557	.0105	20, 000	0. 510	65, 190	.2550
7, 000	0. 026	22, 816	,0130	21, 000	0. 559	68, 449	.2795
8, 000	0. 035	26, 076	.0175	22, 000	0. 642	71, 709	.3210
9, 000	0. 051	29, 335	.0255				
10, 000	0. 080	32, 595	.0400				
11, 000	0. 119	35, 854	.0595				

Piece removed slightly bent.
Surface wrinkled.

TESTS BY TORSIONAL STRESS.

MECHANICAL LABORATORY, DEPARTMENT OF ENGINEERING, STEVENS INSTITUTE OF TECHNOLOGY.

TABLE CXXXVII.—COPPER AND TIN ALLOYS—1ST SERIES.

RESULTS OF TESTS CALCULATED FROM THE AUTOGRAPHIC STRAIN DIAGRAM.

No.	Area of diagram.	Angle of torsion.	Maximum ordinate.	Ordinate at elastic limit.	Maximum torsional moment.	Torsional moment at elastic limit.	Ductility, extension of exterior fiber.	Resilience.	Remarks.	Diameter.	Equivalent maximum torsional moment of piece ⅝ inch diameter.
	Sq. in.	*Deg.*	*Ins.*	*Ins.*	*Ft. lbs.*	*Ft. lbs.*		*Ft. lbs.*		*Inches.*	
1 A..	1.15	49.0	0.40	0.17	57.83	30.82	0.0351	32.85			
1 C..	0.86	26.5	0.45	0.20	63.70	34.34	0.0104	22.64			
1 D..	1.90	46.0	0.55	0.20	75.46	34.34	0.0310	47.65			
2 A..	25.70	296.0	1.08	0.25	137.39	40.22	0.8990	582.78			
2 B..	24.30	339.0	1.30	0.20	163.53	34.34	1.1021	562.23			
2 C..	11.65	177.0	0.80	0.20	104.81	34.34	0.3890	272.28	Defective; several blowholes.		
2 D..	10.09	169.0	0.75	0.30	99.04	46.09	0.3600	238.80	Defective; several blowholes.		
3 A..	42.25	373.0	1.45	0.30	181.15	46.09	1.2669	936.56			
3 B..	13.70	168.5	1.00	0.38	128.30	55.50	0.3581	312.69			
3 C..	29.50	286.0	1.25	0.40	157.66	57.83	0.8529	658.77			
3 D..	22.50	162.0	1.28	0.35	160.60	52.56	0.3344	491.82			
4 A..	17.74	166.0	1.40	0.35	175.28	51.96	0.3490	395.03			
4 B..	13.22	136.0	1.40	0.35	175.28	51.96	0.2451	296.70			
4 C..	8.10	90.0	1.10	0.53	140.04	71.94	0.1140	183.05			
4 D..	10.40	110.5	1.18	0.50	149.45	69.58	0.1676	234.08			
5 A..	12.70	122.5	1.40	0.40	175.28	57.83	0.2026	283.49			
5 B..	0.95	39.0	0.38	0.20	55.48	34.34	0.0224	26.85	Defective; large cavity.		
5 C..	11.98	106.5	1.40	0.65	175.28	87.20	0.1564	265.70			
5 D..	5.10	68.0	0.95	0.40	122.43	57.83	0.0666	117.40	Defective; several blowholes.		
6 A..	6.36	69.5	1.15	0.50	145.92	69.58	0.0694	143.51	Defective through liquation.		
6 B..	11.45	100.0	1.46	0.60	182.82	81.32	0.1391	253.61			
6 C..	7.95	87.0	1.14	0.45	144.74	63.69	0.1068	179.41	Defective through liquation.		
6 D..	5.82	61.0	1.05	0.55	134.17	75.45	0.0539	130.83	Defective through liquation.		
7 A..	1.45	14.0	1.38	1.25	172.93	157.66	0.0029	32.37			
7 B..	0.30	5.0	1.78	0.78	102.46	102.46	0.0004	7.10	Defective; large cavity.		
7 C..	1.89	21.8	1.65	0.70	204.64	93.07	0.0065	42.85			
7 D..	1.42	13.0	1.55	0.80	192.89	104.81	0.0025	31.56			
8 A..	0.07	3.0	0.90	0.90	116.55	116.55	0.0013	2.00			
8 B..	0.22	4.0	1.02	1.02	130.65	130.65	0.0024	5.27			
8 C..	0.16	3.0	1.05	1.05	134.17	134.17	0.0018	3.85			
8 D..	0.15	3.5	0.82	0.82	107.16	107.16	0.0019	3.74			
9 D..	0.08	1.5	1.50	1.50	64.90	64.90	0.0008	0.63		0.970	17.58
11 A..	0.12	0.75	3.40	3.40	58.51	58.51	0.0002	0.36		0.955	16.44
12 A..	0.08	1.0	1.20	1.20	21.10	21.10	0.0003	0.25		0.900	7.06
13 C..	0.10	1.0	1.45	1.45	32.41	32.41	0.0003	0.41		0.960	8.94
14 D..	0.06	1.0	2.80	2.80	48.31	48.31	0.0003	0.19		0.955	13.54
15 B..	0.09	1.0	3.70	3.70	63.62	63.62	0.0003	0.28		0.965	17.28
15 D..	0.09	1.0	2.45	2.45	42.35	42.35	0.0003	0.28		0.940	12.45
16 A..	0.07	1.0	1.30	1.30	56.47	56.47	0.0003	0.54		0.945	16.34
16 B..	0.09	0.5	2.15	2.15	102.30	102.30	0.0001	0.68		0.945	29.60
16 C..	0.12	1.25	4.00	4.00	68.72	68.72	0.0004	0.37		0.890	23.80
17 A..	0.05	2.0	1.45	1.45	62.79	62.79	0.0013	0.43		0.940	18.46
17 C..	0.12	1.2	2.20	2.20	94.41	94.41	0.0004	0.92		0.922	29.41
17 D..	0.10	1.75	1.65	1.65	36.45	36.45	0.0004	0.45		0.625	36.45
18 A..	0.05	1.0	1.05	1.05	45.93	45.93	0.0008	0.40		0.895	15.64
18 C..	0.10	2.5	1.20	1.20	27.37	27.37	0.0009	0.49			
18 D..	0.08	1.6	1.20	1.20	27.37	27.37	0.0004	0.37			

TESTS BY TORSIONAL STRESS—Continued.

No.	Area of diagram.	Angle of torsion.	Maximum ordinate.	Ordinate at elastic limit.	Maximum torsional moment.	Torsional moment at elastic point.	Ductility, extension of exterior fiber.	Resilience.	Remarks.
	Sq. in.	*Deg.*	*Ins.*	*Ins.*	*Ft. lbs.*		*Ft. lbs.*	*Ft. lbs.*	
19 A..	0.02	1.1	0.33	0.38	9.83	9.83	0.00002	0.13	
19 B..	0.14	2.75	1.28	1.28	29.00	29.00	0.00010	0.64	
19 D..	0.02	1.75	0.38	0.38	10.84	10.84	0.00004	0.17	
20 A..	0.01	0.5	0.38	0.38	10.84	10.84	0.00001	0.63	Large crystalline, weakest; fine granular, strongest.
20 B..	0.30	4.5	1.60	1.60	35.44	35.44	0.00030	1.30	Blowhole in center
20 C..	0.20	2.6	1.10	1.10	25.35	25.35	0.00009	0.85	
20 D..	0.04	1.75	0.45	0.45	12.24	12.24	0.00004	0.24	
21 A..	0.57	4.5	1.90	1.86	41.50	40.63	0.00030	2.25	
22 A..	0.43	5.5	1.15	1.15	26.36	26.36	0.0005	1.82	
22 B..	1.26	1.0	1.50	1.20	83.43	27.37	0.0015	4.99	
22 C..	0.20	4.0	0.82	0.80	19.70	19.30	0.0002	0.92	
22 D..	0.10	3.25	0.46	0.45	12.24	12.24	0.00015	0.53	
23 A..	2.78	26.5	1.15	0.83	26.36	19.91	0.0103	11.24	
23 C..	1.64	22.0	0.85	0.60	20.31	15.26	0.0072	6.98	
23 D..	2.18	26.0	0.92	0.65	21.72	16.31	0.0100	8.93	
24 A..	1.28	16.5	0.90	0.63	21.32	15.90	0.0040	5.41	
24 B..	8.13	79.5	1.08	0.60	24.95	15.30	0.0899	32.99	
24 C..	9.88	109.0	1.10	0.55	25.35	14.26	0.1634	40.77	
24 D..	3.50	42.0	0.90	0.60	21.32	15.26	0.0250	14.63	
25 A..	11.88	153.0	0.90	0.50	21.32	13.25	0.3024	48.47	
25 B..	10.95	102.5	1.30	0.70	29.39	17.28	0.1456	44.18	
25 C..	9.30	123.5	0.85	0.45	20.31	12.24	0.2057	39.53	
25 D..	9.96	148.0	0.88	0.60	20.91	15.26	0.2851	43.20	
26 A..	7.45	117.0	0.70	0.40	17.28	11.23	0.1863	32.66	Blowhole in center; defective.
26 B..	18.05	251.0	0.80	0.45	19.30	12.24	0.6953	77.34	
26 C..	13.18	213.0	0.70	0.33	17.28	9.84	0.5328	58.11	Blowhole in center; defective.
26 D..	18.40	190.0	1.15	0.40	26.36	11.23	0.4401	75.22	
27 A..	14.38	277.0	0.68	0.18	16.78	6.91	0.8118	65.85	Blowhole in center; defective.
27 B..	20.75	362.5	0.70	0.30	17.28	9.21	1.2156	92.98	
27 C..	18.50	412.5	0.80	0.22	19.30	7.19	1.4620	87.81	
27 D..	15.86	334.5	0.55	0.22	14.26	7.19	1.0804	74.22	Blowhole in center; defective.
28 A..	1.14	259.0	0.10	0.00	5.17	0.00	0.7308	72.39	(Defective test.) Diagram incorrect. Tested with 100 pounds upon arm.
28 B..	34.25	610.0	0.68	0.15	16.78	6.30	2.4741	154.11	
28 C..	26.30	504.0	0.70	0.20	17.38	7.19	1.9260	120.30	
28 D..	21.73	492.0	0.60	0.20	15.26	7.19	1.8637	103.55	
29 A..	25.10	591.0	0.55	0.15	14.26	6.18	2.3750	120.86	
29 B..	21.16	516.0	0.55	0.12	14.26	5.58	1.9863	102.86	
29 C..	21.95	524.0	0.50	0.15	13.25	6.18	2.0278	106.08	
29 D..	16.82	596.0	0.30	0.10	9.21	5.17	2.4010	91.99	
30 A..	10.72	105.0	1.22	0.50	127.49	54.41	0.1524	195.89	
30 B..	18.23	158.0	1.40	0.40	145.13	44.32	0.3201	331.69	
30 C..	21.27	177.0	1.40	0.50	145.13	54.41	0.3900	386.49	
30 D..	20.20	172.0	1.50	0.45	155.21	49.36	0.3712	307.32	

NOTE.—In making up the averages of results given in the table on pages 330, 378, the pieces marked defective in the above table are rejected.

Bars No. 1 to No. 8, inclusive, and No. 30, were tested with 100-pound weight on arm of torsion machine. Nos. 9 D, 16 A, 16 B, 17 A, 17 C, and 18 A were tested with 30-pound weight, and the remainder without any weight on arm.

The pieces were all 0.625 inch diameter except Nos. 9 D to 18 A, inclusive. The diameters of these are given in the column headed "Remarks." The torsional moment of the piece is given in the table, and in the column of "Remarks" is given the equivalent torsional moment of a piece of standard size, which is found by dividing the moment as found from the diagram by the ratio of the cube of the diameter of the piece to the cube of 0.625 inch, the torsional strength varying as the cube of the diameter. The resilience of the pieces is the resilience of the piece as tested, and not that of a specimen of standard size. The latter cannot be given, as at present the relation of the torsional resilience to diameter is unknown.

RECORD OF TESTS BY TRANSVERSE STRESS.

[*Second series.*]

MECHANICAL LABORATORY, DEPARTMENT OF ENGINEERING, STEVENS INSTITUTE OF TECHNOLOGY.

TABLE CXXXVIII.—ALLOY OF COPPER AND TIN.

Original mark: No. 31.—Material: Alloy.—Original mixture: 97.5 Cu, 2.5 Sn.—Dimensions: Length between supports, $l = 22''$. Breadth, $b = 0.956''$. Depth, $d = 0.977''$.

Load.	Deflection. Δ	Set.	Modulus of elasticity. $E = \frac{Pl^3}{4 \Delta b d^3}$
Pounds.	*Inches.*	*Inches.*	
10	0.0110		
20	0.0145		
40	0.0207		5,769,739
80	0.0321		7,441,347
120	0.0433		8,274,843
160	0.0552		8,654,608
200	0.0674		8,860,059
3		0.0109	
240	0.0822		8,717,780
280	0.0982		8,513,596
320	0.1188		8,042,667
360	0.1568		6,855,244

Resistance decreases slowly.

On putting on 380 pounds, a crack was found on the under side of bar. The resistance decreased as the deflection was increased, till the bar broke.

Breaking load, 360 pounds.

Modulus of rupture, $R = \frac{3\,Pl}{2\,bd^2} = 13,014$.

The fracture was full of blowholes, and was partly oxidized, showing that the crack was an old one.

(Bar defective; test worthless.)

TABLE CXXXIX.—ALLOY OF COPPER AND TIN.

Original mark: No. 32.—Material: Alloy.—Original mixture: 92.5 Cu, 7.5 Sn.—Dimensions: Length between supports, $l = 22''$. Breadth, $b = 0.956''$. Depth, $d = 0.982''$.

Load.	Deflection. Δ	Set.	Modulus of elasticity. $E = \frac{Pl^3}{4 \Delta b d^3}$
Pounds.	*Inches.*	*Inches.*	
10	0.0060		
20	0.0104		
40	0.0185		6,357,759
80	0.0278		8,461,765
120	0.0376		9,384,459
160	0.0472		9,967,673
200	0.0572		10,281,341
3		0.0035	
240	0.0678		10,564,538
280	0.0769		10,706,500
320	0.0880		10,692,594
360	0.0983		10,768,738
400	0.1105		10,644,211
3		0.0145	
440	0.1232	Beam sinks	10,501,656
480	0.1389		10,161,420
520	0.1535		9,961,177
560	0.1719		9,579,171
600	0.1963		8,987,663
3		0.0577	
600	0.2065		
Pounds.	*Inches.*	*Inches.*	
3		0.0655	
600	0.2095		
640	0.2365		7,957,281
680	0.2867		
720	0.3511		6,080,003
760	0.4609		
800	0.6031		3,900,466
3		0.4118	
800	0.6202		
840	0.7792		
880	1.0427		
920	1.3217		
960	1.74		
1,000	2.13		1,380,404
1,040	2.63		
1,080	3.78		840,132
3		8.40	

Resistance decreased in 2^m to 586 pounds.
Resistance decreased in $1^h\ 48^m$ to 562 pounds.

Bar bent to deflection of 8″ without breaking.

Breaking load (or the load causing deflection of 3½″) 1,080 pounds.

Modulus of rupture, $R = \frac{3}{2}\frac{Pl}{bd^2} = 38,659$.

RECORD OF TESTS BY TRANSVERSE STRESS—Continued.

[*Second series.*]

MECHANICAL LABORATORY, DEPARTMENT OF ENGINEERING, STEVENS INSTITUTE OF TECHNOLOGY.

TABLE CXL.—ALLOY OF COPPER AND TIN.

Original mark: No. 33.—**Material:** Alloy.—**Original mixture:** 87.5 Cu, 12.5 Sn.—**Dimensions:** Length between supports, 22″. Breadth, 0.978″. Depth, 0.977″.

Load.	Deflection. Δ	Set.	Modulus of elasticity. $E=\frac{Pl^3}{4\Delta bd^3}$	Load.	Deflection. Δ	Set.	Modulus of elasticity. $E=\frac{Pl^3}{4\Delta bd^3}$
Pounds.	*Inches.*	*Inches.*		*Pounds.*	*Inches.*	*Inches.*	
10	0.0042			1,000	0.3245		
20	0.0075			3		0.0910	
40	0.0125		9,387,752	1,040	0.3611		
80	0.0236		9,969,873	1,080	0.3959		8,002,946
120	0.0332		10,603,633	1,120	0.4493		
160	0.0409		11,478,087	1,160	0.5122		
200	0.0508		11,549,891	1,200	0.5727		6,147,034
3		0.0049		3		0.2827	
240	0.0606		11,618,503	1,200	0.5892		
280	0.0701		11,717,949	1,240	0.6475		
320	0.0793		11,838,275	1,280	0.7485		
360	0.0890		11,869,273	1,300	0.8111		
400	0.0960		11,974,171	1,320	0.8701		
3		0.0036(?)		1,360	0.9892		
440	0.1071		12,052,435	1,400	1.1419		3,596,760
480	0.1168			1,440	1.3032		
520	0.1255		12,155,454	1,480	1.4878		
560	0.1355		12,127,844	1,520	1.6700		
600	0.1461		12,047,936	1,560	1.8500		
3		0.0112		1,600	2.1000		2,235,179
640	0.1568			1,640	2.4500		
680	0.1678		11,888,540	1,680	2.1000		
720	0.1800	Beam sinks slowly.		1,700	3.5000		1,424,927
760	0.1933			3		2.81	
800	0.2074		11,315,997	1,700			
3		0.0284					
840	0.2269						
880	0.2475						
920	0.2716		9,937,327				
960	0.2964						

Bar broke after a deflection of about 4″.
Breaking load 1,700 pounds.

Modulus of rupture, $R=\frac{3\,Pl}{2\,bd^2}=60{,}403.$

TABLE CXLI.—ALLOY OF COPPER AND TIN.

Original mark: No. 34.—**Material:** Alloy.—**Original mixture:** 82.5 Cu, 17.5 Sn.—**Dimensions:** Length between supports, 22″. Breadth, 0.950″. Depth, 0.970″.

10	0.0060			1,000	0.2060		14,903,838
20	0.0080			10		0.0098	
40	0.0135		9,096,944	1,040	0.2157		14,802,137
80	0.0227		10,820,152	1,080	0.2264		
120	0.0316		11,659,056	1,120	0.2377		14,466,320
160	0.0405		12,129,260	1,100	0.2472		
200	0.0481		12,765,982	1,200	0.2614		
10		0.0035		1,240	0.2728		
240	0.0560		13,158,079	1,280	0.2852		
280	0.0646		13,307,417	1,320	0.3003		13,495,466
320	0.0729		13,476,957	1,360	0.3175		
360	0.0804		13,747,250	1,400	0.3330		
400	0.0881		13,939,699	10		0.0436	
10		0.0035		1,440	0.3495		
440	0.0940		14,371,235	1,480	0.3693		
480	0,1027		14,349,611	1,520	0.3880		12,055,389
520	0.1099		14,526,967	1,560	0.4170		
560	0.1174		14,644,993	1,600	0.4393		
600	0.1265		14,562,305	10		0.0985	
10		0.0028		1,640	0.4575		
640	0.1340		14,663,731	1,680	0.4825		
680	0.1409		14,817,235	1,720	0.5247		10,064,370
720	0.1473		15,007,180	1,760	0.5464		
760	0.1549		15,063,694	1,800	0.5757		
800	0.1631		15,059,318	1,840	0.6125		9,223,187
10		0.0051					
800	0.1618						
Resistance decreased in $19^h\ 45^m$ to 788 pounds.							
10		0.0047					
840	0.1702		15,152,664				
880	0.1790		15,093,815				
920	0.1873		16,080,625				
960	0.1959		14,045,481				

Broke suddenly with a ringing sound about 30 seconds after putting on the strain, and just after reading the deflection.

Breaking load, 1,840 pounds.

Modulus of rupture, $R=\frac{3\,Pl}{2\,bd^2}=67{,}930.$

RECORD OF TESTS BY TRANSVERSE STRESS—Continued.

[*Second series.*]

MECHANICAL LABORATORY, DEPARTMENT OF ENGINEERING, STEVENS INSTITUTE OF TECHNOLOGY.

TABLE CXLII.—ALLOY OF COPPER AND TIN.

Original mark: No. 35.—Material: Alloy.—Original mixture: 77.5 Cu, 22.5 Sn.—Dimensions: Length between supports, 22″. Breadth, 0.965″. Depth, 0.968″.

Load.	Deflection. Δ	Set.	Modulus of elasticity. $E = \frac{Pl^3}{4 \Delta bd^3}$	Load.	Deflection. Δ	Set.	Modulus of elasticity. $E = \frac{Pl^3}{4 \Delta bd^3}$
Pounds.	*Inches.*	*Inches.*		*Pounds.*	*Inches.*	*Inches.*	
10	0.0032	....	....	480	0.0994	....	14,686,206
20	0.0055	....	....	520	0.1059	....	14,967,942
40	0.0095	....	12,805,342	560	0.1145	....	14,874,825
80	0.0180	....	13,516,751	600	0.1229	....	14,847,529
120	0.0276	....	13,222,905	3	....	0.0038	....
160	0.0358	....	13,592,263	640	0.1308	....	14,880,829
200	0.0436	....	13,950,775	680	0.1385	....	14,931,859
8	....	0.0035	....	720	0.1458	....	15,018,612
240	0.0519	....	14,063,667	760	0.1528	....	15,126,728
280	0.0601	....	14,168,971	800	0.1606	....	15,149,535
820	0.0689	....	14,092,421	3	....	0.0045	....
860	0.0766	....	14,293,167	840	Broke in putting on strain.		
400	0.0852	....	14,278,257				
8	....	0.0035	....				
440	0.0932	....	14,357,924				

Breaking load, 820 pounds.

Modulus of rupture, $R = \frac{3}{2} \frac{Pl}{bd^2} = 29,926.$

TABLE CXLIII.—ALLOY OF COPPER AND TIN.

Original mark: No. 36.—Material: Alloy (second casting).—Original mixture: 72.5 Cu, 27.5 Sn.—Dimensions: Length between supports, 22″. Breadth, 0.998″. Depth, 1.004″.

Load.	Deflection.	Set.	Modulus of elasticity.	Load.	Deflection.	Set.	Modulus of elasticity.
10	0.0013	....	....	240	0.0386	....	16,387,041
20	0.0036	....	....	260	0.0422	....	16,238,179
40	0.0077	....	13,691,334	280	0.0453	....	16,290,571
80	0.0143	....	14,744,515	290	0.0475	....	16,090,922
120	0.0208	....	15,205,280	300	Broke in applying strain.		
160	0.0276	....	15,278,736				
200	0.0329	....	16,021,775				
4	....	0.0013	....				
200	0.0330	....	....				
220	0.0358	....	16,196,313				

Breaking load, 290 pounds.

Modulus of rupture, $R = \frac{3}{2} \frac{Pl}{bd^2} = 9,512.$

TABLE CXLIV.—ALLOY OF COPPER AND TIN.

Original mark: No. 37.—Material: Alloy.—Original mixture: 67.5 Cu, 32.5 Sn.—Dimensions: Length, between supports, 22″. Breadth, 9.965″. Depth, 0.987″.

Load.	Deflection.	Set.	Modulus of elasticity.	Load.	Deflection.	Set.	Modulus of elasticity.
10	0.0068	....	....	200	0.0403	....	14,238,174
20	0.0097	....	....	5	....	0.0032	....
30	0.0116	....	....	220	0.0435	....	14,509,843
40	0,0133	....	8,628,548	240	0.0466	....	14,775,922
60	0.0161	....	10,691,894	260	0.0501	....	14,888,979
80	0.0199	....	11,533,636	270	0.0520	....	14,896,691
100	0.0239	....	12,473,879	280	Broke in applying strain.		
120	0.0280	....	12,295,678				
140	0.0313	....	12,832,669				
160	0.0341	....	13,461,545				
180	0.0375	....	13,771,159				

Breaking load, 270 pounds.

Modulus of rupture, $R = \frac{3}{2} \frac{Pl}{bd^2} = 9,477.$

RECORD OF TESTS BY TRANSVERSE STRESS—Continued.

[*Second series.*]

MECHANICAL LABORATORY, DEPARTMENT OF ENGINEERING, STEVENS INSTITUTE OF TECHNOLOGY.

TABLE CXLV.—ALLOY OF COPPER AND TIN.

Original mark: No. 38 (E—F).—Material: Alloy.—Original mixture: 62.5 Cu, 37.5 Sn.—Dimensions: Length between supports, 9″. Breadth, 0.985″. Depth, 0.995″. Middle portion of original bar.

Load.	Deflection. Δ	Set.	Modulus of elasticity. $\frac{Pl^3}{4\Delta bd^3}$
Pounds.	*Inches.*	*Inches.*	
12	0.0035		
42	0.0065		1,218,662
80	0.0125		
100	0.0135		1,391,324
120	0.0145		
140	0.0155		1,696,517
0		0.0035	
140	0.0155		
160	0.0163		1,623,297
180	0.0173		1,954,287
200	0.0185		2,030,581
220	Broke in applying strain.		

Breaking load, 210 pounds.

Modulus of rupture, $R=\frac{3}{2}\frac{Pl}{bd^2}=2{,}907$.

The irregularity of the first three deflections given above was caused by the bar not resting evenly on the supports. It was slightly warped, and at the beginning of the test only the corners touched the supports. The corners appeared to be crushed at the lower pressures below 80 pounds.

TABLE CXLVI.—ALLOY OF COPPER AND TIN.

Original mark: No. 39 (B—E).—Material: Alloy.—Original mixture: 57.5 Cu, 42.5 Sn.—Dimensions: Length between supports, 17″. Breadth, 1″. Depth, 0.985″. Lower portion of original bar.

Load.	Deflection. Δ	Set.	Modulus of elasticity. $E=\frac{Pl^3}{4\Delta bd^3}$
Pounds.	*Inches.*	*Inches.*	
22	0.0042		
42	0.0085		6,350,411
62	0.0105		7,588,929
82	0.0132		7,983,956
102	0.0150		8,739,548
122	0.0180		8,710,948
142	0.0210		8,690,546

Broke about 20 seconds after applying strain.
Breaking load, 142 pounds.

Modulus of rupture, $R=\frac{3}{2}\frac{Pl}{bd^2}=3{,}732$.

TABLE CXLVII.—ALLOY OF COPPER AND TIN.

Original mark: No. 40 (A—E).—Material: Alloy.—Original mixture: 52.5 Cu, 47.5 Sn.—Dimensions: Length between supports, 9″. Breadth, 1.015″. Depth, 1″. Upper portion of original bar.

Load.	Deflection. Δ	Set.	Modulus of elasticity. $E=\frac{Pl^3}{4\Delta bd^3}$
Pounds.	*Inches.*	*Inches.*	
21	0.0020		
41	0.0037		1,989,682
61	0.0050		2,190,591
81	0.0055		2,644,380
101	0.0065		2,790,034
121	0.0071		3,060,051
141	0.0080		3,164,686
161	Broke in applying strain.		

Breaking load, 150 pounds.

Modulus of rupture, $R=\frac{3}{2}\frac{Pl}{bd^2}=1{,}995$.

RECORD OF TESTS BY TRANSVERSE STRESS—Continued.

[*Second series.*]

MECHANICAL LABORATORY, DEPARTMENT OF ENGINEERING, STEVENS INSTITUTE OF TECHNOLOGY.

TABLE CXLVIII.—ALLOY OF COPPER AND TIN.

Original mark: No. 41 (A—F).—Material: Alloy.—Original mixture: 47.5 Cu, 52.5 Sn.—Dimensions: Length between supports, 15″. Breadth, 0.962″. Depth, 0.980″. Upper portion of original bar.

Load.	Deflection. Δ	Set.	Modulus of elasticity. $E=\frac{Pl^3}{4\Delta bd^3}$	Load.	Deflection. Δ	Set.	Modulus of elasticity. $E=\frac{Pl^3}{4\Delta bd^3}$
Pounds.	*Inches.*	*Inches.*		*Pounds.*	*Inches.*	*Inches.*	
10	0.0018			180	0.0167		10,044,225
20	0.0030			200	0.0180		10,354,234
40	0.0047		7,930,902	4		0.0022	
60	0.0036		8,875,059	220	0.0186		11,022,256
80	0.0075		9,940,064	240	Broke in applying strain.		
100	0.0098		9,508,991				
120	0.0115		9,723,976				
140	0.0134		9,736,077				
160	0.0151		9,874,239				

Breaking load, 230 pounds.

Modulus of rupture, $R=\frac{3}{2}\frac{Pl}{bd^2}=5{,}601.$

TABLE CXLIX.—ALLOY OF COPPER AND TIN.

Original mark: No. 42 (A—F).—Material: Alloy.—Original mixture: 42.5 Cu, 57.5 Sn.—Dimensions: Length between supports, 18″. Breadth, 0.995″. Depth, 0.995″.

Load.	Deflection.	Set.	Modulus of elasticity.	Load.	Deflection.	Set.	Modulus of elasticity.
22	0.0083			202	0.0319		9,419,455
42	0.0060		10,412,693	222	0.0357		9,250,174
82	0.0124		9,836,878	227	Broke in applying strain 5 inches from A end.		
102	0.0158		9,603,038				
122	0.0188		9,653,107				
142	0.0215		9,824,600				
162	0.0249		9,677,893				
182	0.0285		9,499,300				

Breaking load, 222 pounds.

Modulus of rupture, $R=\frac{3}{2}\frac{Pl}{bd^2}=6{,}084.$

TABLE CL.—ALLOY OF COPPER AND TIN.

Original mark: No. 42 (F—C).—Material: Alloy.—Piece remaining after previous test, 13 inches long.—Dimensions: Length between supports, 12″.

Load.	Deflection.	Set.	Modulus of elasticity.	Load.	Deflection.	Set.	Modulus of elasticity.
22	0.0022			322	0.0282		5,032,666
42	0.0043		4,304,986	362	0.0310		4,862,456
82	0.0091		3,971,584				
122	0.0132		4,078,589				
162	0.0164		4,353,740				
202	0.0202		4,407,490				
242	0.0220		4,848,239				
282	0.0264		4,708,000				

Broke just as strain was applied.

Breaking load, 362 pounds.

Modulus of rupture, $R=\frac{3}{2}\frac{Pl}{bd^2}=6{,}605.$

TABLE CLI.—ALLOY OF COPPER AND TIN.

Original mark: No. 43.—Material: Alloy.—Original mixture: 37.5 Cu, 62.5 Sn.—Dimensions: Length between supports, 22″. Breadth, 0.970″. Depth, 0.990″.

Load.	Deflection.	Set.	Modulus of elasticity.	Load.	Deflection.	Set.	Modulus of elasticity.
10	0.0038			160	0.0577		7,842,870
20	0.0050		11,313,836	180	0.0676		7,531,069
40	0.0106		10,672,961	200	0.0799		7,079,685
60	0.0169		10,041,426	6		0.0202	
80	0.0228		9,923,982	200	Broke just as beam rose.		
100	0.0308		9,182,904				
	Beam sinks slowly.						
120	0.0389		8,724,939				
140	0.0482		8,215,079				

Breaking load, 200 pounds.

Modulus of rupture, $R=\frac{3}{2}\frac{Pl}{bd^2}=6{,}942.$

RECORD OF TESTS BY TRANSVERSE STRESS—Continued.

[*Second series.*]

MECHANICAL LABORATORY, DEPARTMENT OF ENGINEERING, STEVENS INSTITUTE OF TECHNOLOGY.

TABLE CLII.—ALLOY OF COPPER AND TIN.

Original mark: No. 44.—**Material:** Alloy.—**Original mixture:** 32.5 Cu, 67.5 Sn.—**Dimensions:** Length between supports, 22″. Breadth, 0.985″. Depth, 0.990″.

Load.	Deflection. Δ	Set.	Modulus of elasticity. $E=\frac{Pl^3}{4\Delta bd^3}$
Pounds.	*Inches.*	*Inches.*	
10	0.0019	....	....
20	0.0075	....	7,427,369
40	0.0176	....	6,330,144
60	0.0247	....	6,765,822
80	0.0319	....	6,984,987
100	0.0406	....	6,860,256
	Beam sinks slowly.		
120	0.0505	....	6,618,447
140	0.0607	....	6,424,002
160	0.0743	....	5,997,876
180	0.0907	....	5,527,535
200	0.1098	....	5,078,241
6	....	0.0325	....
200	0.1122	....	....
	Heard several slight cracks.		
210	Bar broke just as beam rose.		

Breaking load, 210 pounds.

Modulus of rupture, $R=\frac{3}{2}\frac{Pl}{bd^2}=7{,}178.$

TABLE CLIII.—ALLOY OF COPPER AND TIN.

Original mark: No. 45.—**Material:** Alloy.—**Original mixture:** 27.5 Cu, 72.5 Sn.—**Dimensions:** Length between supports, 22″. Breadth, 0.978″.. Depth, 0.985″.

Load.	Deflection. Δ	Set.	Modulus of elasticity. $\frac{Pl^3}{4\Delta bd^3}$
Pounds.	*Inches.*	*Inches.*	
10	0.0026	....	....
20	0.0061	....	9,338,147
40	0.0146	....	7,803,107
80	0.0325	....	7,010,792
	Beam sinks slowly.		
100	0.0403	....	7,067,332
120	0.0487	....	7,017,989
140	0.0583	....	6,839,430
160	0.0696	....	6,547,436
5	....	0.0145	....
160	0.0720	....	....
4	....	0.0400	....
100	0.0763	....	....
120	0.0817	....	....
140	0.0887	....	....
160	0.0970	....	....
180	0.1053	....	4,868,606
200	0.1162	....	4,902,125
220	0.1297	....	4,831,069
240	0.1480	....	....
260	0.1647	....	4,496,144
280	0.1846	....	....
300	0.2057	....	4,153,819
4	....	0.0873	....
300	0.2073	....	....
310	0.2204	....	4,005,997
320	Broke just as beam rose.		

Resistance to strain decreased in 1 min. to 154 pounds.

Resistance to strain decreased in 3 min. to 150 pounds.

Resistance to strain decreased in 44 hours to 104 pounds.

Resistance to strain decreased in 69 hours to 100 pounds.

Breaking load, 320 pounds.

Modulus of rupture, $R=\frac{2}{3}\frac{Pl}{bd^2}=11{,}128.$

TABLE CLIV.—ALLOY OF COPPER AND TIN.

Original mark: No. 46.—**Material:** Alloy.—**Original mixture:** 22.5 Cu, 77.5 Sn.—**Dimensions:** Length between supports, 22″. Breadth, 0.980″. Depth, 0.992″.

10	0.0036	....	....
20	0.0066	....	8,432,047
40	0.0141	....	7,893,831
60	0.0197	....	8,474,849
80	0.0272	....	8,182,160
100	0.0363	....	7,665,497
	Beam sinks slowly.		
4	....	0.0047	....
120	0.0460	....	7,258,892
140	0.0579	....	6,728,160
160	0.0709	....	6,279,437
180	0.0868	....	5,770,317
200	0.1045	....	5,325,503
4	....	0.0357	....
220	0.1239	....	....
240	0.1487	....	4,491,042
260	0.1675	....	....
280	0.1923	....	4,051,591
300	0.2203	....	....
4	....	0.1044	....
320	0.2479	....	3,591,869
340	0.2814	....	....
360	0.3163	....	3,167,015
380	0.3523	....	....
400	0.3908	....	2,848,081
10	....	0.2051	....
400	0.4051	....	....
420	Broke in applying strain.		

Breaking load, 400 pounds.

Modulus of rupture, $R=\frac{2}{3}\frac{Pl}{bd^2}=13{,}687.$

RECORD OF TESTS BY TRANSVERSE STRESS—Continued.

[*Second series.*]

MECHANICAL LABORATORY, DEPARTMENT OF ENGINEERING, STEVENS INSTITUTE OF TECHNOLOGY.

TABLE CLV.—ALLOY OF COPPER AND TIN.

Original mark: No. 47.—Material: Alloy.—Original mixture: 17.5 Cu, 82.5 Sn.—Dimensions: Length between supports, 22″. Breadth, 0.996″. Depth, 0.983″.

Load.	Deflection. Δ	Set.	Modulus of elasticity. $\frac{Pl^3}{4 \Delta bd^3}$
Pounds.	*Inches.*	*Inches.*	
10	0.0027		
20	0.0070		8,039,339
40	0.0153		7,356,258
60	0.0256		6,594,770
80	0.0365		6,167,163
	Beam sinks slowly.		
100	0.0499		5,638,814
5		0.0092	
120	0.0617		5,472,481
140	0.0804		4,899,597
160	0.1042		4,320,565
180	0.1343		3,771,245
200	0.1666		3,377,873
5		0.0821	
200	0.1798		
220	0.2145		
240	0.2503		2,697,980
260	0.3021		
270	0.3367		
280	0.3762		832,406
290	0.4147		
300	0.4597		
5		0.3084	

The beam was observed to rise, and another reading of set was taken in 2 minutes.

5		0.3022	

The beam rose again, pushed forward the poise till beam balanced at 10 pounds.

Time, 2 minutes.

In 2 minutes more beam balanced at 14 pounds.

The pressure-screw was then run back till beam balanced again at 5 pounds, and another reading of set taken.

Pounds.	*Inches.*	*Inches.*	
5		0.2998	

Beam rose again.

In 2 minutes balanced at 10 pounds.

In 10 minutes balanced at 16 pounds.

In 39 minutes balanced at 23 pounds.

Ran back pressure-screw till beam balanced again at 5 pounds.

5		0.2902	

In 4 minutes beam rose again.

In 23 minutes beam balanced at 14 pounds.

In 1 hour and 36 minutes beam balanced at 20 pounds.

Ran back pressure-screw till beam balanced again at 5 pounds.

5		0.2845	

Total *decrease of set* in 2 hours and 20 minutes, 0.3084−0.2845=0.0239 inches.

Replaced load of 280 pounds.

280	0.4849		
300	0.5332		
310	Broke on applying strain.		

Breaking load, 300 pounds.

Modulus of rupture, $R = \frac{3}{2} \frac{Pl}{bd^2} = 10,288$.

TABLE CLVI.—ALLOY OF COPPER AND TIN.

Original mark: No. 48.—Material: Alloy.—Original mixture: 12.5 Cu, 87.5 Sn.—Dimensions: Length between supports, 22″. Breadth, 0.985″. Depth, 0.990.″.

10	0.0025		
20	0.0050		
40	0.0141		7,901,458
60	0.0230		7,249,195
80	0.0352		6,330,144
	Beam sinks slowly.		
100	0.0508		5,482,803
5		0.0120	
120	0.0769		4,397,784
140	0.0969		4,024,116
160	0.1262		3,531,237
180	0.1592		
200	0.2044		2,725,307
5		0.1238	
200	0.2263		
220	0.2916		
240	0.4078		1,639,194
260	0.5210		
270	0.5763		
280	0.6458		1,207,609
290	0.7185		
300	0.8025		1,041,220
5		0.6742	

Scale beam rose.

In 2 minutes balanced at 20 pounds.

In 4 minutes balanced at 29 pounds.

In 15 minutes balanced at 34 pounds.

Ran back pressure-screw till beam balanced again at 5 pounds.

5		0.6555	

Beam rose again, balanced at 12 pounds in 5 minutes.

5		0.6508	

Total decrease of set in 20 minutes, 0.6742−0.6508=0.0234 inches.

Beam rose again, but test was continued without further waiting.

260	0.8304		
280	0.9018		
300	1.0760	Beam sank rapidly.	
300	Repeated.	Bar broke just as beam rose.	

Breaking load, 300 pounds.

Modulus of rupture, $R = \frac{3}{2} \frac{Pl}{bd^2} = 10,254$.

RECORD OF TESTS BY TRANSVERSE STRESS—Continued.

[*Second series.*]

MECHANICAL LABORATORY, DEPARTMENT OF ENGINEERING, STEVENS INSTITUTE OF TECHNOLOGY.

TABLE CLVII.—ALLOY OF COPPER AND TIN.

Original mark: No. 49.—Material: Alloy.—Original mixture: 7.5 Cu, 92.5 Sn.—Dimensions: Length between supports, 22″. Breadth, 0.990″. Depth, 0.995″.

Load.	Deflection. Δ	Set.	Modulus of elasticity. $\frac{Pl^3}{4\Delta bd^3}$	Load.	Deflection. Δ	Set.	Modulus of elasticity. $\frac{Pl^3}{4\Delta bd^3}$
Pounds.	*Inches.*	*Inches.*		*Pounds.*	*Inches.*	*Inches.*	
10	0.0009			3		0.2872	
20	0.0087			220	0.5232		
40	0.0137		7,960,719	240	0.8017		817,152
60	0.0233		7,020,089	250	0.10072		
80	0.0367		5,963,860	260	1.3300		
	Beam sinks.			270	1.7800		
100	0.0537		5,083,424	280	2.6700		286,253
3		0.0128		290	3.6700		215,693
120	0.0751		4,361,591				
140	0.1153						
160	0.1587		2,751,969				
180	0.2382						
200	0.3582		1,524,081				

Bar bent without breaking.

Breaking load (or load causing deflection of 3½ inches), 290 pounds.

Modulus of rupture, $R=\frac{3}{2}\frac{Pl}{bd^2}=9,764$.

TABLE CLVIII.—ALLOY OF COPPER AND TIN.

Original mark: No. 50.—Material: Alloy.—Original mixture: 2.5 Cu, 97.5 Sn.—Dimensions: Length between supports, 22″. Breadth, 0.991″. Depth, 0.997″.

10	0.0032		8,470,302	210	0.8512		
20	0.0081		6,692,585	Repeated—			
40	0.0221		4,905,876	210	1.0322		
60	0.0331		4,918,288	210	1.0800		
	Beam sinks slowly.			220	1.3800		432,108
80	0.0472		4,594,063	230	1.6800		
100	0.0629		4,309,216	240	2.4300		
4		0.0164		250	3.9300		172,423
120	0.0909		3,578,218				
140	0.1418		2,676,090				
160	0.2217		1,956,154				
180	0.3777						
200	0.5797		985,188				
4		0.5042					
200	0.6912						

Bar bent without breaking.

Breaking load (or load causing 3½ inches deflection), 250 pounds.

Modulus of rupture, $R=\frac{3}{2}\frac{Pl}{bd^2}=8,375$.

RECORD OF TESTS BY TENSILE STRESS.

[*Second series.*]

MECHANICAL LABORATORY, DEPARTMENT OF ENGINEERING, STEVENS INSTITUTE OF TECHNOLOGY.

TABLE CLIX.—ALLOY OF COPPER AND TIN.

Original mark: No. 31 A.—Material: Alloy.—Original mixture: 97.5 Cu, 2.5 Sn.—Dimensions: Length, 5″. Diameter, 0.798″.

Load per square inch.	Elongation in 5 inches.	Set.	Elongation in parts of original length.
Pounds.	*Inches.*	*Inches.*	
800	0.0010		.0002
2,000	0.0042		.0008
3,000	0.0079		.0016
4,000	0.0123		.0025
200		0.0030	
5,000	0.0172		.0034
6,000	0.0230		.0046
7,000	0.0306		.0061
8,000	0.0373		.0075
200		0.0230	
9,000	0.0455		.0091
10,000	0.0530		.0106
11,000	0.0617		.0123
12,000	0.0699		.0139
200		0.0620	
13,000	0.0849		.0170

Broke just as reading was taken ½ inch from C end.

Diameter of fractured section, 0.770 inch.

Fracture full of small blowholes.

Tenacity per square inch, original section, 13,000 pounds.

Tenacity per square inch, fractured section, 13,958 pounds.

RECORD OF TESTS BY TENSILE STRESS—Continued.

[*Second series.*]

MECHANICAL LABORATORY, DEPARTMENT OF ENGINEERING, STEVENS INSTITUTE OF TECHNOLOGY.

TABLE CLX.—ALLOY OF COPPER AND TIN.

Original mark: No. 31 B.—**Material:** Alloy.—Original mixture: 97.5 Cu, 2.5 Sn.—**Dimensions:** Length, 5″. Diameter, 0.798″.

Load per square inch.	Elongation in 5 inches.	Set.	Elongation in parts of original length.
Pounds.	*Inches.*	*Inches.*	
800	0.0010	....	.0002
2,000	0.0025	....	.0005
4,000	0.0055	....	.0011
200	....	0.0005	....
5,000	0.0077	....	.0015
6,000	0.0103	....	.0021
7,000	0.0131	....	.0026
8,000	0.0168	....	.0034
200	....	0.0081	....
10,000	0.0247	....	.0049
12,000	0.0348	....	.0070
200	....	0.0273	....
14,000	0.0531	....	.0106
15,000	0.0666	....	.0133
15,250	0.0773	....	.0155

Broke 2 inches from D end after taking reading.

Diameter of fractured section, 0.770 inch; full of blowholes.

Tenacity per square inch, original section, 15,250 pounds.

Tenacity per square inch, fractured section, 16,374 pounds.

The bar was defective in consequence of separation of metals, and blowholes throughout its whole length.

TABLE CLXI.—ALLOY OF COPPER AND TIN.

Original mark: No. 32 A.—**Material:** Alloy.—Original mixture: 92.5 Cu, 7.5 Sn.—**Dimensions:** Length, 5″. Diameter, 0.798″.

Load per square inch.	Elongation in 5 inches.	Set.	Elongation in parts of original length.	Load per square inch.	Elongation in 5 inches.	Set.	Elongation in parts of original length.
Pounds.	*Inches.*	*Inches.*		*Pounds.*	*Inches.*	*Inches.*	
800	0.0010	....	.0002	200	....	0.0906	....
2,000	0.0027	....	.0005	22,000	0.1509	....	.0302
3,000	0.0039	....	.0008	23,000	0.1793	....	.0359
4,000	0.0051	....	.0010	In 1 min.	0.1916	....	.0393
200	....	0.0011	....	24,000	0.2156	....	.0431
6,000	0.0073	....	.0015	In 20 sec.	0.2218	....	.0444
8,000	0.0091	....	.0018	200	....	0.2110	....
200	....	0.0044	....	26,000	0.3038	....	.0607
10,000	0.0104	....	.0021	28,000	0.3896	....	.0779
12,000	0.0120	....	.0024	28,500	Broke 1 inch from C end.		
200	....	0.0079	....				
14,000	0.0146	....	.0029				
16,000	0.0222	....	.0044				
200	....	0.0181	....				
18,000	0.0506	....	.0101				
In 1 min.	0.0546	....	.0109				
19,000	0.0664	....	.0133				
20,000	0.0956	....	.0191				

Fractured section elliptical, diameters, 0.690 x 0.732 inch.

Tenacity per square inch, original section, 28,500 pounds.

Tenacity per square inch, fractured section, 35,922 pounds.

Several very small blowholes in fractured surface.

TABLE CLXII.—ALLOY OF COPPER AND TIN.

Original mark: No. 32 B.—**Material:** Alloy.—Original mixture: 92.5 Cu, 7.5 Sn.—**Dimensions:** Length, 5″. Diameter, 0.798″.

800	0.0004	....	.0001	200	....	0.0944	....
2,000	0.0038	....	.0008	22,000	0.1516	....	.0313
3,000	0.0062	....	.0012	24,000	0.2135	....	.0417
4,000	0.0085	....	.0017	25,000	0.2399	....	.0480
6,000	0.0138	....	.0028	In 1 min.	0.2594	....	.0519
8,000	0.0203	....	.0041	26,000	0.2980	....	.0596
200	....	0.0039	....	27,000	0.3338	....	.0668
10,000	0.0272	....	.0054	27,300	0.3532	....	.0706
12,000	0.0363	....	.0072				
200	....	0.0199	....				
14,000	0.0459	....	.0092				
16,000	0.0554	....	.0111				
200	....	0.0449	....				
18,000	0.0707	....	.0141				
20,000	0.1044	....	.0208				

Broke ¾ inch from D end.

Fractured section elliptical, diameters, 0.735 x 0.720 inch.

Tenacity per square inch, original section, 27,300 pounds.

Tenacity per square inch, fractured section, 32,844 pounds.

RECORD OF TESTS BY TENSILE STRESS—Continued.

[*Second series.*]

MECHANICAL LABORATORY, DEPARTMENT OF ENGINEERING, STEVENS INSTITUTE OF TECHNOLOGY.

TABLE CLXIII.—ALLOY OF COPPER AND TIN.

Original mark: No. 33 A.—**Material:** Alloy.—**Original mixture:** 87.5 Cu, 12.5 Sn.—**Dimensions:** Length, 5″. Diameter, 0.798″.

Load per square inch.	Elongation in 5 inches.	Set.	Elongation in parts of original length.	Load per square inch.	Elongation in 5 inches.	Set.	Elongation in parts of original length.
Pounds.	*Inches.*	*Inches.*		*Pounds.*	*Inches.*	*Inches.*	
1, 200	0. 0022		.0004	20, 000	0. 0405		.0081
2, 000	0. 0044		.0009	200		0. 0261	
3, 000	0. 0072		.0014	22, 000	0. 0485		.0097
4, 000	0. 0093		.0019	24, 000	0. 0605		.0121
200		0. 0005		200		0. 0467	
6, 000	0. 0128		.0026	26, 000	0. 0804		.0161
8, 000	0. 0185		.0037	27, 000	0. 0927		.0185
200		0. 0008		28, 000	0. 1129		.0226
10, 000	(?) 0. 0184		.0037	200		0. 0955	
12, 000	0. 0218		.0044	29, 000	Broke in middle just as beam rose.		
200		0. 0037					
14, 000	0. 0246		.0049				
16, 000	0. 0292		.0058				
200		0. 0114					
18, 000	0. 0342		.0068				

Diameter of fractured section, 0.776 inch.

Tenacity per square inch, original section, 29,000 pounds.

Tenacity per square inch, fractured section, 30,658 pounds.

TABLE CLXIV.—ALLOY OF COPPER AND TIN.

Original mark: No. 33 B.—**Material:** Alloy.—**Original mixture:** 87.5 Cu, 12.5 Sn.—**Dimensions:** Length, 5″. Diameter, 0.798″.

1, 200	0. 0025		.0005	24, 000	0. 0905		.0191
2, 000	0. 0052		.0010	200		0. 0665	
3, 000	0. 0097		.0019	26, 000	0. 1040		.0208
4, 000	0. 0139		.0028	28, 000	0. 1271		.0254
6, 000	0. 0206		.0041	200		0. 1063	
8, 000	0. 0275		.0055	30, 000	0. 1561		.0312
200		—0.0008(?)		32, 000	0. 2007		.0401
10, 000	0. 0330		.0066	200		0. 1811	
12, 000	0. 0396		.0079	33, 000	0. 2270		.0454
200		0. 0049		33, 200	0. 2432		.0485
14, 000	0. 0473		.0094				
16, 000	0. 0541		.0108				
200		0. 0200					
18, 000	0. 0623		.0125				
20, 000	0. 0709		.0142				
200		0. 0421					
22, 000	0. 0793		.0159				

Broke in middle.

Diameter of fractured section, 0.770 inch.

Tenacity per square inch, original section, 33,200 pounds.

Tenacity per square inch, fractured section, 35,648 pounds.

TABLE CLXV.—ALLOY OF COPPER AND TIN.

Original mark: No. 34 A.—**Material:** Alloy.—**Original mixture:** 82.5 Cu, 17.5 Sn.—**Dimensions:** Length, 5″. Diameter, 0.798″.

2, 000	0. 0032		.0006	26, 000	0. 0224		.0045
4, 000	0. 0074		.0015	28, 000	0. 0244		.0049
6, 000	0. 0104		.0021	200		0. 0042	
8, 000	0. 0125		.0025	30, 000	0. 0264		.0053
200		—0.0004(?)		32, 000	0. 0288		.0058
10, 000	0. 0137		.0027	200		0. 0091	
12, 000	0. 0150		.0030	34, 000	0. 0316		.0063
200		0. 0001		37, 300	0. 0357		.0071
14, 000	0. 0161		.0032	40, 200	Broke ¾ inch from A end.		
16, 000	0. 0170		.0034				
18, 000	0. 0176		.0035				
20, 000	0. 0194		.0039				
22, 000	0. 0200		.0040				
24, 000	0. 0216		.0043				
200		0. 0002					

Diameter of fractured section, 0.795 inch.

Tenacity per square inch of original section, 40,200 pounds.

Tenacity per square inch of fractured section, 40,492 pounds.

RECORD OF TESTS BY TENSILE STRESS—Continued.

[*Second series.*]

MECHANICAL LABORATORY, DEPARTMENT OF ENGINEERING, STEVENS INSTITUTE OF TECHNOLOGY.

TABLE CLXVI.—ALLOY OF COPPER AND TIN.

Original mark: No. 34 B.—**Material:** Alloy.—**Original mixture:** 82.5 Cu, 17.5 Sn.—**Dimensions:** Length, 5″. Diameter, 0.798″.

Load per square inch.	Elongation in 5 inches.	Set.	Elongation in parts of original length.	Load per square inch.	Elongation in 5 inches.	Set.	Elongation in parts of original length.
Pounds.	*Inches.*	*Inches.*		*Pounds.*	*Inches.*	*Inches.*	
2,000	0.0019	....	.0004	22,000	0.0216	....	.0043
3,000	0.0034	....	.0007	24.000	0.0244	....	.0049
4,000	0.0054	....	.0011	200	....	+0.0021	....
6,000	0.0080	....	.0016	26,000	0.0269	....	.0054
8,000	0.0110	....	.0022	28,000	0.0296	....	.0059
10,000	0.0119	....	.0024	30,000	0.0324	....	.0065
12,000	0.0136	....	.0027	32,000	0.0355	....	.0071
14,000	0.0149	....	.0030	200	....	0.0139	....
16,000	0.0170	....	.0034	32,200	Broke at shoulder, B end.		
18,000	0.0179	....	.0026	Diameter of fractured section, 0.798 inch.			
20,000	0.0200	....	.0040	Tenacity per square inch of original section, 32,200 pounds.			
200	....	—0.0022(?)	....				

TABLE CLXVII.—ALLOY OF COPPER AND TIN.

Original mark: No. 35 A.—**Material:** Alloy.—**Original mixture:** 77.5 Cu, 22.5 Sn.—**Dimensions:** Length, 5″. Diameter, 0.798″.

Load per square inch.	Elongation in 5 inches.	Set.	Elongation in parts of original length.	Load per square inch.	Elongation in 5 inches.	Set.	Elongation in parts of original length.
2,000	0.0016	....	.0003	20,000	0.0198	....	.0039
4,000	0.0060	....	.0012	21,000	0.0197	....	.0039
6,000	0.0094	....	.0019	22,000	0.0203	....	.0041
8,000	0.0124	....	.0025	23,000	0.0207	....	.0042
10,000	0.0128	....	.0026	23,600	Broke 1 inch from A end.		
12,000	0.0143	....	.0029	Diameter of fractured section, 0.798 inch.			
14,000	0.0161	....	.0032	Tenacity per square inch, original section, 23,600 pounds.			
16,000	0.0175	....	.0035				
18,000	0.0180	....	.0036				

TABLE CLXVIII.—ALLOY OF COPPER AND TIN.

Original mark: No. 35 B.—**Material:** Alloy.—**Original mixture:** 77.5 Cu, 22.5 Sn.—**Dimensions:** Length, 5″. Diameter, 0.798″.

Load per square inch.	Elongation in 5 inches.	Set.	Elongation in parts of original length.	Load per square inch.	Elongation in 5 inches.	Set.	Elongation in parts of original length.
1,200	0.0014	....	.0003	16,000	0.0264	....	.0053
2,000	0.0040	....	.0008	18,000	0.0281	....	.0056
3,000	0.0068	....	.0014	20,000	0.0299	....	.0060
4,000	0.0100	....	.0020	22,000	0.0310	....	.0062
6,000	0.0142	....	.0028	24,000	0.0324	....	.0065
8,000	0.0178	....	.0036	25,000	0.0329	....	.0066
10,000	0.0199	....	.0039	25,700	Broke in middle.		
12,000	0.0224	....	.0045	Diameter of fractured section, 0.798 inch.			
14,000	0.0246	....	.0049	Tenacity per square inch, 25,700 pounds.			

RECORDS OF TESTS BY TENSILE STRESS—Continued.

[*Second series.*]

MECHANICAL LABORATORY, DEPARTMENT OF ENGINEERING, STEVENS INSTITUTE OF TECHNOLOGY.

TABLE CLXIX.—ALLOY OF COPPER AND TIN.

Original mark: No. 36 A.—**Material:** Alloy.—**Original mixture:** 72.5 Cu, 27.5 Sn.—**Rectangular section** 0.998″ x 1.002″. Too brittle to be turned

At 3,860 pounds, the piece broke in the upper jaw of the tensile machine, 1⅛ inches from A end. Set again in machine. At 6,500 pounds broke in lower jaw, 1 inch from C end. Piece too short to be tested further.

Tenacity per square inch, 6,500 pounds.
Elongation not measured.

TABLE CLXX.—ALLOY OF COPPER AND TIN.

Original mark: No. 36 B.—**Material:** Alloy.—**Original mixture:** 72.5 Cu, 27.5 Sn.—**Rectangular section,** 1.010″ x 1.000″.

At 6,550 pounds, broke in lower jaw, 1⅛ inches from B end.

6,050 pounds, broke 3 inches from bottom and 1 inch above edge of lower jaw.

6,300 pounds, broke at edge of lower jaw, 2⅛ inches from B end.

Breaking load, 6,550 pounds.
Tenacity per square inch, 6,485 pounds.

NOTE.—It appears that the brittle pieces break in the jaws of the machine partly by crushing and partly by tensile strain. The figures obtained for tenacity are, therefore, probably too low.

TABLE CLXXI.—ALLOY OF COPPER AND TIN.

Original mark: No. 37 A.—**Material:** Alloy.—**Original mixture:** 67.5 Cu, 32.5 Sn.—**Rectangular section,** 0.975″ x 0.990″.

At 1,606 pounds, broke in lower jaw, 1⅛ inches from A end.

At 940 pounds, broke in upper jaw, 1¼ inches from C end.

At 1,240 pounds, broke in upper jaw.
Breaking load, 1,606 pounds.
Tenacity per square inch, 1,664 pounds.

TABLE CLXXII.—ALLOY OF COPPER AND TIN.

Original mark: No. 37 B.—**Material:** Alloy.—**Original mixture:** 67.5 Cu, 32.5 Sn.—**Rectangular section,** 0.982″ x 0.985″.

At 2,014 pounds, broke in lower jaw by crushing.

At 1,536 pounds, broke in upper jaw, 2 inches from end.

At 1,334 pounds, broke in upper jaw; crushed off ⅛ inch.

At 3,304 pounds, broke in lower jaw, 1 inch from end.

At 2,408 pounds, broke in upper jaw, ½ inch from end.

At 3,150 pounds, broke in upper jaw, 1⅛ inches from end.

At 3,330 pounds, broke in lower jaw, ⅜ inch from end.

Too short to test further.
Breaking load (maximum), 3,330 pounds.
Tenacity per square inch, 3,408 pounds.

TABLE CLXXIII.—ALLOY OF COPPER AND TIN.

Original mark: No. 38 A.—**Material:** Alloy.—**Original mixture:** 62.5 Cu, 37.5 Sn.—**Rectangular section,** 0.980″ x 0.992″.

Tested 4 times; broke each time in upper jaw, at 1,282, 2,270, 1,980, and 1,520 pounds.

Breaking load (maximum), 2,270 pounds.
Tenacity per square inch, 2,335 pounds.

TABLE CLXXIV.—ALLOY OF COPPER AND TIN.

Original mark: No. 38 B.—**Material:** Alloy.—**Original mixture:** 62.5 Cu, 37.5 Sn.—**Rectangular section,** 0.983″ x 0.990″.

Broke in jaws at 766 pounds.

Tenacity per square inch, 787 pounds.

RECORDS OF TESTS BY TENSILE STRESS—Continued.

[*Second series.*]

MECHANICAL LABORATORY, DEPARTMENT OF ENGINEERING, STEVENS INSTITUTE OF TECHNOLOGY.

TABLE CLXXV.—ALLOY OF COPPER AND TIN.

Original mark: No. 39 A.—**Material:** Alloy.—Original mixture: 57.5 Cu, 42.5 Sn.—Rectangular section 0.982″ x 0.990″.

Tested 4 times; broke in jaws each time, at 800, 266, 1,166, and 944 pounds.

Breaking load (maximum), 1,166 pounds.
Tenacity per square inch, 1,200 pounds.

TABLE CLXXVI.—ALLOY OF COPPER AND TIN.

Original mark: No. 39 B.—**Material:** Alloy.—Original mixture: 57.5 Cu, 42.5 Sn.—Rectangular section, 0.988″ x 0.997″.

Broke in jaws, at 966 and 1,530 pounds.
Breaking load (maximum), 1,530 pounds.
Tenacity per square inch, 1,553 pounds.

[No. 40 was broken by the transverse test into pieces too short for tests by tension.]

TABLE CLXXVII.—ALLOY OF COPPER AND TIN.

Original mark: No. 41 (A—C).—**Material:** Alloy.—Original mixture: 47.5 Cu, 52.5 Sn.—Rectangular section, 0.968″ x 0.985″.

Tested 4 times; broke in jaws each time, at 1,830, 1,730, 690, and 1,360 pounds.

Tested a fifth time, when the piece broke in the middle, at 1,720 pounds.

Breaking load (maximum), 1,830 pounds.
Tenacity per square inch, 1,919 pounds.

TABLE CLXXVIII.—ALLOY OF COPPER AND TIN.

Original mark: No. 41 (E—D).—**Material:** Alloy.—Original mixture: 47.5 Cu, 52.5 Sn.—Rectangular section, 0.962″ x 0.985″.

At 1,340 pounds, broke 2 inches from E end.
At 1,160 pounds, broke in jaws ¼ inch from E end.
At 1,320 pounds, broke 2 inches from D end.

Breaking load (maximum), 1,340 pounds.
Tenacity per square inch, 1,414 pounds.

TABLE CLXXIX.—ALLOY OF COPPER AND TIN.

Original mark: No. 41 (B—E).—**Material:** Alloy.—Original mixture: 47.5 Cu, 52.5 Sn.—Rectangular section, 0.960″ x 0.990″.

At 2,120 pounds, broke 1 inch from E end.
At 2,750 pounds, broke 2 inches from E end.

Breaking load, 2,750 pounds.
Tenacity per square inch, 2,894 pounds.

TABLE CLXXX.—ALLOY OF COPPER AND TIN.

Original mark: No. 42 (C—E).—**Material:** Alloy.—Original mixture: 42.5 Cu, 57.5 Sn.—Rectangular section, 0.992″ x 1.004″.

Tested 4 times; broke in jaws each time, at 760, 2,204, 1,470, and 1,034 pounds.

Breaking load (maximum), 2,264 pounds.
Tenacity per square inch, 2,273 pounds.

TABLE CLXXXI.—ALLOY OF COPPER AND TIN.

Original mark: No. 42 (F—B).—**Material:** Alloy.—Original mixture: 42.5 Cu, 57.5 Sn.—Rectangular section, 0.955″ x 0.987″.

Broke at 1,890 pounds, 8 inches from B end.

Tenacity per square inch, 1,924 pounds.

RECORD OF TESTS BY TENSILE STRESS—Continued.

[*Second series.*]

MECHANICAL LABORATORY, DEPARTMENT OF ENGINEERING, STEVENS INSTITUTE OF TECHNOLOGY.

TABLE CLXXXII.—ALLOY OF COPPER AND TIN.

Original mark: No. 43 A.—**Material:** Alloy.—**Original mixture:** 37.5 Cu, 62.5 Sn.—**Dimensions:** Length, 5″. Diameter. 0.798.″

Broke in middle at 1,400 pounds. Elongation less than 0.01 inch.	Tenacity per square inch, 2,800 pounds.

TABLE CLXXXIII.—ALLOY OF COPPER AND TIN.

Original mark: No. 43 B.—**Material:** Alloy.—**Original mixture:** 37.5 Cu, 62.5 Sn.—**Dimensions:** Length, 5″. Diameter, 0.798″.

Broke 1 inch from B end, at 1,000 pounds. Elongation less than 0.01 inch.	Tenacity per square inch, 2,000 pounds.

TABLE CLXXXIV.—ALLOY OF COPPER AND TIN.

Original mark: No. 44 A.—**Material:** Alloy.—**Original mixture:** 32.5 Cu, 67.5 Sn.—**Dimensions:** Length, 5″. Diameter, 0.798″.

Broke in middle, at 796 pounds. Elongation less than 0.01 inch.	Tenacity per square inch, 1,592 pounds.

TABLE CLXXXV.—ALLOY OF COPPER AND TIN.

Original mark: No. 44 B.—**Material:** Alloy.—**Original mixture:** 32.5 Cu, 67.5 Sn.—**Dimensions:** Length, 5″. Diameter, 0.798″.

Broke at shoulder, D end, at 1,526 pounds. No elongation detected.	Tenacity, 3,052 pounds per square inch.

TABLE CLXXXVI.—ALLOY OF COPPER AND TIN.

Original mark: No. 45 A.—**Material:** Alloy.—**Original mixture:** 27.5 Cu, 72.5 Sn.—**Dimensions:** Length, 5″. Diameter, 0.798″.

Broke at 1,680 pounds, 1⅓ inches from C end.	Tenacity, 3,360 pounds per square inch.

TABLE CLXXXVII.—ALLOY OF COPPER AND TIN.

Original mark: No. 45 B.—**Material:** Alloy.—**Original mixture:** 27.5 Cu, 72.5 Sn.—**Dimensions:** Length, 5″. Diameter, 0.798″.

Broke at 2,700 pounds, 1⅓ inches from D end.	Tenacity, 5,400 pounds per square inch.

TABLE CLXXXVIII.—ALLOY OF COPPER AND TIN.

Original mark: No. 46 A.—**Material:** Alloy.—**Original mixture:** 22.5 Cu, 77.5 Sn.—**Dimensions:** Length, 5″. Diameter, 0.798″.

Broke at 2,100 pounds, 1 inch from C end. Elongation not measured.	Tenacity, 4,200 pounds per square inch.

RECORD OF TESTS BY TENSILE STRESS—Continued.

[*Second series.*]

MECHANICAL LABORATORY, DEPARTMENT OF ENGINEERING, STEVENS INSTITUTE OF TECHNOLOGY.

TABLE CLXXXIX.—ALLOY OF COPPER AND TIN.

Original mark: No. 46 B.—Material: Alloy.—Original mixture: 22.5 Cu, 77.5 Sn.—Dimensions: Length, 5″. Diameter, 0.798″.

Load per square inch.	Elongation in 5 inches.	Set.	Elongation in parts of original length.
Pounds.	*Inches.*	*Inches.*	
800	0.0615	....	.0003
1,600	0.0058	....	.0012
2,000	0.0070	....	.0014
2,400	0.0090	....	.0018
2,800	0.0109	....	.0023
3,200	0.0124	....	.0025
3,600	0.0140	....	.0027
4,000	0.0157	....	.0031
200	....	0.0096	....
4,000	0.0164	....	.0033
5,000	0.0182	....	.0036
5,800	0.0213	....	.0043

Broke just as beam rose 1½ inches from B end.

Diameter of fractured section, 0.796 inch.

Tenacity per square inch of original section, 5,800 pounds.

Tenacity per square inch of fractured section, 5,827 pounds.

TABLE CXC.—ALLOY OF COPPER AND TIN.

No. 47 A.—Broke in handling.

ALLOY OF COPPER AND TIN.

Original mark: No. 47 B.—Material: Alloy.—Original mixture: 17.5 Cu, 82.5 Sn.—Dimensions: Length, 5″. Diameter, 0.798″.

Broke at 1,408 pounds, 1½ inches from D end.
Elongation not measured.
Tenacity, 2,816 pounds per square inch.

Diameter of fractured section, 0.797 inch.

Tenacity per square inch of fractured section, 2,822 pounds.

TABLE CXCI.—ALLOY OF COPPER AND TIN.

Original mark: No. 48 A.—Material: Alloy.—Original mixture: 12.5 Cu, 87.5 Sn.—Dimensions: Length, 5″. Diameter, 0.798″.

Broke in middle, at 1,708 pounds.
Elongation not measured.
Diameter of fractured section, 0.795 inch.

Tenacity per square inch of original section, 3,416 pounds.

Tenacity per square inch of fractured section, 3,440 pounds.

TABLE CXCII.—ALLOY OF COPPER AND TIN.

Original mark: No. 48 B.—Material: Alloy.—Original mixture: 12.5 Cu, 87.5 Sn.—Dimensions: Length, 5″. Diameter, 0.798″.

Load per square inch.	Elongation in 5 inches.	Set.	Elongation in parts of original length.
Pounds.	*Inches.*	*Inches.*	
800	0.0022	....	.0004
1,600	0.0097	....	.0019
2,000	0.0160	....	.0032
2,400	0.0224	....	.0045
200	....	0.0172	....
2,800	0.0810	....	.0062
3,200	0.0407	....	.0081
4,000	0.0551	....	.0110
200	....	0.0496	....
4,180	Broke in middle.		

Diameter of fractured section, 0.795 inch.

Tenacity per square inch, original section, 4,180 pounds.

Tenacity per square inch, fractured section, 4,210 pounds.

RECORD OF TESTS BY TENSILE STRESS—Continued.

[*Second series.*]

MECHANICAL LABORATORY, DEPARTMENT OF ENGINEERING, STEVENS INSTITUTE OF TECHNOLOGY.

TABLE CXCIII.—ALLOY OF COPPER AND TIN.

Original mark: No. 49 A.—**Material:** Alloy.—**Original mixture:** 7.5 Cu, 92.5 Sn.—**Dimensions:** Length, 5″. Diameter, 0.798″.

Load per square inch.	Elongation in 5 inches.	Set.	Elongation in parts of original length.
Pounds.	*Inches.*	*Inches.*	
3, 200	0. 0065		. 0013
4, 000	0. 0278		. 0056
200		0. 0247	
4, 400	0. 0472		. 0094
5, 000	0. 1109		. 0222
6, 192	0. 7945		. 1580
Surface of piece corrugated by strain. Reduced strain to—			
4, 800	0. 8709		. 1742
5, 000	Broke in middle.		

Breaking load, 6,192 pounds per square inch.

Diameter of fractured section. 0.710 inch.

Tenacity per square inch of original section, 6,192 pounds.

Tenacity per square inch, fractured section (assuming that the final section sustained the last recorded load, 5,000 pounds per square inch original section), 6,315 pounds. Dividing the maximum load by the final area, the apparent tenacity per square inch of fractured section is 7,981 pounds.

TABLE CXCIV.—ALLOY OF COPPER AND TIN.

Original mark: No. 49 B.—**Material:** Alloy.—**Original mixture:** 7.5 Cu, 92.5 Sn.—**Dimensions:** Length, 5″. Diameter, 0.798″.

Load per square inch.	Elongation in 5 inches.	Set.	Elongation in parts of original length.
Pounds.	*Inches.*	*Inches.*	
800	0. 0019		. 0004
1, 600	0. 0067		. 0013
2, 000	0. 0121		. 0024
200		0. 0 66	
2, 400	0. 0176		. 0035
2, 800	0. 0265		. 0053
3, 200	0. 0335		. 0067
4, 000	0. 0440		. 0088
200		0. 0420	
4, 400	0. 0510		. 0102
4, 800	0. 0633		. 0127
5, 200	0. 0905		. 0181
5, 600	0. 1245		. 0249
6, 000	0. 1815		. 0363
6, 000	Continued 3 minutes; piece extended and finally broke. Last reading of elongation, just before fracture, 1.1508 inches, 23.02.		

Diameter of fractured section, 0.680 inch.

Tensile strength per square inch, original section, 6,000 pounds.

Tensile strength per square inch, fractured section, 8,260 pounds.

TABLE CXCV.—ALLOY OF COPPER AND TIN.

Original mark: No. 50 A.—**Material:** Alloy.—**Original mixture:** 2.5 Cu, 97.5 Sn.—**Dimensions:** Length, 5″. Diameter, 0.798″.

Load per square inch.	Elongation in 6 inches.	Set.	Elongation in parts of original length.
Pounds.	*Inches.*	*Inches.*	
1, 200	0. 0061		. 0012
1, 600	0. 0124		. 0025
2, 000	0. 0236		. 0047
2, 400	0. 0356		. 0071
2, 800	0. 0493		. 0099
3, 200	0. 0596		. 0119
3, 600	0. 0691		. 0138
4, 000	0. 0926		. 0185
4, 400	0. 1158		. 0232
4, 800	0. 1601		. 0320
5, 200	0. 2496		. 0499
5, 600	0. 4391		. 0878
5, 600	Continued 2 minutes. Elongation		

increased to 1.8260 or 36.52 per cent., when the micrometer would not follow it further. The resistance to strain then gradually decreased to 2,200 pounds per square inch, when the piece broke in the middle. Total elongation measured after fracture, 2.05 inches; per cent. of length, 41.00.

Diameter of fractured section, 0.545 inch.

Tensile strength per square inch of original section, 5,600 pounds.

Tensile strength per square inch of fractured section (assuming that the final section sustained the last observed load, viz, 1,100 pounds), 4,500 pounds.

Dividing the maximum load (2,800 pounds) by the final area, the apparent tenacity per square inch of fractured section is 12,002 pounds.

RECORD OF TESTS BY TENSILE STRESS—Continued.

[*Second series.*]

MECHANICAL LABORATORY, DEPARTMENT OF ENGINEERING, STEVENS INSTITUTE OF TECHNOLOGY.

TABLE CXCVI.—ALLOY OF COPPER AND TIN.

Original mark: No. 50 B.—Material: Alloy.—Original mixture: 2.5 Cu, 97.5 Sn.—Dimensions: Length, 5″. Diameter, 0.798″.

Load per square inch.	Elongation in 5 inches.	Set.	Elongation in parts of original length.
Pounds.	*Inches.*	*Inches.*	
1,200	0.0057	....	.0011
2,000	0.0255	....	.0051
200	....	0.0195	....
2,400	0.0347	....	.0069
2,800	0.0460	....	.0092
3,200	0.0515	....	.0103
3,600	0.0707	....	.0141
4,000	0.0775	....	.0155
200	....	0.0757	....
4,400	0.0945	....	.0189
4,800	0.1275	....	.0255
5,200	0.1900	....	.0380
5,600	0.3275	....	.0655
5,600	Continued 2 minutes.		
Piece extended rapidly.			
Resistance decreased to 5,000, at which it continued for 1 minute.			
5,000	1.8120	....	.3624

Resistance decreased further and piece broke 2 inches from B end.

Total extension, measured after breaking, 1.98 inches; per cent. of length, 39.00.

Diameter of fractured section, 0.530 inch.

Tenacity per square inch of original section, 5,600 pounds.

Tenacity per square inch of fractured section (dividing maximum load by final area), 12,691 pounds.

RECORD OF TESTS BY COMPRESSIVE STRESS.

MECHANICAL LABORATORY, DEPARTMENT OF ENGINEERING, STEVENS INSTITUTE OF TECHNOLOGY.

TABLE CXCVII.—CAST COPPER (FLUXED WITH FLUOR SPAR).

Material: Cast copper.—Laboratory number: 525.—Dimensions: Length, 2″. Diameter, 0.625.″

Load.	Compression.	Load per square inch.	Compression in parts of original length.	Load.	Compression.	Load per square inch.	Compression in parts of original length.
Pounds.	*Inches.*	*Pounds.*		*Pounds.*	*Inches.*	*Pounds.*	
1,000	0.002	3,259	.0010	13,000	0.345	42,373	.1725
2,000	0.007	6,519	.0035	14,000	0.415	45,633	.2075
3,000	0.010	9,778	.0050	15,000	0.474	48,892	.2370
4,000	0.015	13,038	.0075	16,000	0.552	52,152	.2760
5,000	0.019	16,297	.0095	16,500	0.581	53,782	.2905
6,000	0.022	19,557	.0110	17,000	0.611	55,411	.3055
7,000	0.028	22,816	.0140	17,500	0.648	57,041	.3240
8,000	0.048	26,076	.0240	22,000	1.26	71,709	.6300
9,000	0.092	29,335	.0460				
10,000	0.146	32,595	.0730				
11,000	0.201	35,854	.1005				
12,000	0.279	39,114	.1395				

Removed piece.

At 9,000 pounds a slight double curve was observed; at 10,000 the resistance decreased to 9,700 in 2 minutes.

RECORD OF TESTS BY TORSIONAL STRESS.

[*Second series.*]

TABLE CXCVIII.—COPPER AND TIN ALLOYS.

RESULTS OF TESTS, CALCULATED FROM THE AUTOGRAPHIC STRAIN DIAGRAMS.

	Number.	Area of diagram.	Angle of torsion.	Ordinate.		Torsional moment.		Ductility extension of exterior fiber.	Resilience.	Remarks.		
				Maximum.	At elastic limit.	Maximum.	At elastic limit.					
		Sq. in.	*Degrees.*	*Inches.*	*Inches.*	*Ft.-lbs.*	*Ft.-lbs.*		*Ft.-lbs.*			
Tested with 100 pounds weight on arm of machine.	31 A..	3.55	53	0.85	0.30	89.69	34.24	0.0409	66.14	Defective bar.		
	B..	0.80	29	0.35	0.20	39.28	24.16	0.0124	16.10	Defective bar.		
	C..	1.46	28	0.65	0.30	69.53	34.24	0.0116	27.64	Defective bar.		
	D..	1.97	41	0.63	0.30	67.51	34.24	0.0247	37.51	Defective bar.		
	32 A..	20.99	204	1.45	0.40	150.17	44.32	0.4960	383.45			
	B..	20.41	207	1.50	0.40	155.22	44.32	0.5082	373.46			
	C..	16.75	153	1.50	0.50	155.82	55.27	0.3024	306.32			
	D..	22.58	185	1.60	0.60	165.30	64.49	0.4206	410.10			
	33 A..	9.96	73	1.75	0.65	180.42	69.53	0.0768	180.29			
	B..	6.72	55	1.55	0.60	160.85	65.83	0.0440	122.29			
	C..	11.65	82	1.80	0.70	185.46	74.57	0.0955	210.65			
	D..	10.38	73	1.80	0.60	185.46	64.49	0.0763	187.63		Diameter.	Equivalent torsional moment, standard size.
	34 A..	1.91	14	1.90	0.90	195.54	94.73	0.0029	34.57			
	B..	1.66	13	1.95	0.90	200.58	94.73	0.0025	30.11			
	C..	3.51	21	2.15	1.00	220.74	104.81	0.0065	63.21			
	D..	0.85	8	1.70	1.10	175.38	114.89	0.0010	15.51			
	35 A..	0.32	4	1.50	1.40	155.22	145.13	0.0002	5.91			
	B..	0.61	5.5	2.10	1.60	215.70	165.29	0.0004	11.11			
	C..	0.31	5	1.00	0.80	104.81	84.65	0.0004	5.80			
	D..	0.16	3	1.35	0.40	140.09	44.32	0.0001	3.02			
											Inches.	
30 lbs. weight.	36 A..	0.10	1	3.25	3.25	138.76	138.76	0.00003	0.76		0.975	36.56
100 lbs. weight.	B..	0.05	1	1.28	1.28	133.04	133.04	0.00003	0.91		0.980	34.51
30 lbs. weight.	37 A..	0.18	1.5	2.45	2.45	105.03	105.03	0.00003	1.37		0.970	28.10
	B..	0.10	1.8	2.55	2.55	109.25	109.25	0.0001	0.79		*	*24.15
	38 A..	0.03	0.5	3.15	3.15	134.54	134.54	0.00001	0.24		0.975	35.44
	B..	0.005	0.4	0.20	0.20	10.19	10.19	0.00001	0.05		0.945	2.95
30 pounds weight on arm of machine.	39 — ..	0.02	0.5	0.63	0.63	28.32	28.32	0.00001	0.16		0.930	8.60
	40 A..	0.002	0.3	0.50	0.50	22.84	22.84	0.00001	0.02		0.935	6.82
	B..	0.016	0.5	0.65	0.65	29.16	29.16	0.00001	0.14		0.935	8.71
	41 A..	0.025	1	1.30	1.30	56.56	56.56	0.00003	0.20		0.930	17.17
	B..	0.06	1	1.40	1.40	60.78	60.78	0.00003	0.47		0.925	18.75
	42 A..	0.06	1	1.75	1.75	75.53	75.53	0.00003	0.47		0.960	20.84
	B..	0.12	2	1.80	1.30	56.56	56.56	0.00001	0.94		0.950	16.11
	C..	0.05	1	1.00	1.00	43.91	43.91	0.00003	0.40		0.970	11.75
No weight on arm.	43 A..	0.07	1.5	0.60	0.60	12.38	12.38	0.00004	0.24			
	B..	0.06	2	0.45	0.45	8.82	8.82	0.00006	0.19			
	C..	0.06	1	0.90	0.90	16.50	16.50	0.00002	0.20			
	D..	0.05	1.5	0.70	0.70	13.09	13.09	0.00004	0.18			
	44 A..	0.03	1	0.40	0.40	6.83	6.83	0.00002	0.11			
	B..	0.60	5	1.77	1.70	30.29	29.59	0.0004	1.89			
	C..	0.23	3	0.95	0.95	17.35	17.35	0.0001	0.74			
	D..	0.05	1.5	0.80	0.80	14.79	14.79	0.00004	0.18			
	45 A..	0.07	1.5	0.80	0.80	14.79	14.79	0.00004	0.24			
	C..	0.75	5.5	2.05	1.95	34.98	33.84	0.0004	2.34			
	D..	0.18	2.5	1.50	1.50	26.74	26.74	0.0001	0.59			

RECORD OF TESTS BY TORSIONAL STRESS—Continued.

	Number.	Area of diagram.	Angle of torsion.	Ordinate.		Torsional moment.		Ductility, extension of exterior fiber.	Resilience.	Remarks.
				Maximum.	At elastic limit.	Maximum.	At elastic limit.			
		Sq. in.	*Degrees.*	*Inches.*	*Inches.*	*Ft.-lbs.*	*Ft.-lbs.*		*Ft.-lbs.*	
No weight on arm.	46 A..	0.26	3.5	0.95	0.95	17.35	17.35	0.0002	0.84	
	B..	2.73	16	1.90	1.80	33.56	31.29	0.0038	8.45	
	C..	0.87	6	1.85	1.80	32.71	31.29	0.0005	2.71	
	D..	0.39	4	1.55	1.45	27.59	25.88	0.0002	1.24	
	47 A..	0.18	3	0.95	0.90	17.35	15.98	0.0001	0.60	
	B..	1.70	13	1.55	1.10	27.59	19.49	0.0025	5.32	
	C..	1.08	10.5	1.40	1.12	25.03	19.73	0.0016	8.33	
	D..	2.11	16	1.55	1.30	27.59	23.33	0.0038	6.60	
No weight on arm of machine.	48 A..	6.75	53	1.35	1.07	24.18	18.97	0.0409	21.16	
	B..	8.51	64	1.43	1.15	25.54	20.34	0.0592	26.62	
	C..	7.97	63	1.35	1.10	24.18	19.48	0.0574	24.99	
	D..	6.05	46	1.43	1.05	25.54	18.63	0.0310	18.93	
	49 A..	10.73	125	1.00	0.60	18.21	12.38	0.2103	34.44	
	B..	15.30	186	0.90	0.50	16.50	9.67	0.4245	49.26	
	C..	19.24	180	1.45	0.60	25.89	12.38	0.4014	60.88	Rapid motion.
	D..	18.02	221	1.03	0.50	18.71	9.67	0.5662	58.06	
	50 A..	22.45	325	0.82	0.55	15.22	10.53	1.0352	73.82	
	B..	21.33	348	0.80	0.30	14.79	6.26	1.1453	70.45	
	C..	25.92	350	1.00	0.40	18.21	6.83	1.1550	84.15	
	D..	28.28	424	0.80	0.30	14.79	6.26	1.5400	92.66	

* Rectangular section 0.970″ × 0.975″, reduced to standard section by the formula—

$$V=\frac{\frac{1}{2}\pi r^3}{\frac{1}{4.242}b^3}=V\times .221.$$ V = value of specimen tested. b = side of square specimen. $r = 0.3125$.

RECORD OF TESTS BY TRANSVERSE STRESS.

MECHANICAL LABORATORY, DEPARTMENT OF ENGINEERING, STEVENS INSTITUTE OF TECHNOLOGY.

TABLE CXCIX.—BAR OF CAST COPPER.

Original mark: No. 53.—Material: Copper cast in iron mold.—Dimensions: Length between supports, $l = 22''$. Breadth, 1.0″. Depth, 1.0″.

Load.	Deflection. Δ	Set.	Modulus of elasticity. $\frac{Pl^3}{4\,\Delta\,bd^3}$	Load.	Deflection. Δ	Set.	Modulus of elasticity. $\frac{Pl^3}{4\,\Delta\,bd^3}$
Pounds.	*Inches.*	*Inches.*		*Pounds.*	*Inches.*	*Inches.*	
13	0.0053	....	6,529,433	3	....	0.0150	....
23	0.0095	....	6,444,841	343	0.0970	....	10,443,980
43	0.0165	....	6,937,833	393	0.1130	....	9,258,107
63	0.0245	....	6,845,142	433	0.1305	....	8,832,536
83	0.0315	....	7,014,158	493	0.1765	....	....
93	0.0335	....	7,390,029	543	0.2375	....	....
3	....	0.0085	....	593	0.3335	....	....
113	0.0385	....	7,813,142	643	0.46	....	....
153	0.0495	....	8,227,114	743	0.84	....	....
193	0.0590	....	8,707,912	843	1.88	....	....
3	....	0.0100	....	893	Broke in applying strain.		
213	0.0630	....	9,000,094	Breaking load, about 860 pounds.			
253	0.0735	....	9,163,075	Modulus of rupture, $R=\frac{3}{2}\frac{Pl}{bd^2}=28,380$.			
293	0.0830	....	9,897,187				

RECORD OF TESTS BY TRANSVERSE STRESS—Continued.

MECHANICAL LABORATORY, DEPARTMENT OF ENGINEERING, STEVENS INSTITUTE OF TECHNOLOGY.

TABLE CC.—BAR OF CAST COPPER.

Original mark: No. 54.—Material: Copper cast in iron mold.—Dimensions: $l=22''$. $b=1''$. $d=1''$.

Load.	Deflection. Δ	Set.	Modulus of elasticity. $\frac{Pl^3}{4\Delta bd^3}$	Load.	Deflection. Δ	Set.	Modulus of elasticity. $\frac{Pl^3}{4\Delta bd^3}$
Pounds.	*Inches.*	*Inches.*		*Pounds.*	*Inches.*	*Inches.*	
13	0.0025		13,842,400	443	1.22		
23	0.0046		13,310,000	493	1.68		
43	0.0098		11,680,204	543	2.18		
73	0.0165		11,777,333	593	2.90		
93	0.0240		11,788,856	643	The supports slid from under the bar as it bent under the load. The piece was afterwards bent by pressure at the ends till the ends touched without breaking.		
143	0.0370		10,288,270				
193	0.0620		8,551,503				
243	0.1120						
3		0.0560					
293	0.2400						
343	0.4700						
393	0.80						

Breaking load, P=643 pounds.

Modulus of rupture, $R=\frac{3}{2}\frac{Pl}{bd^2}=21,219$.

TABLE CCI.—BAR OF CAST COPPER.

Original mark: No. 55.—Material: Copper cast in iron mold.—Dimensions: Length between supports, $l=22''$. Breadth, $b=0.985''$. Depth, $d=0.970''$.

Load.	Deflection.	Set.	Modulus of elasticity.	Load.	Deflection.	Set.	Modulus of elasticity.
20	0.0033			480	0.4088		
40	0.0075		15,792,947	500	0.4855		
80	0.0176		13,459,739	5		0.3619	
100	0.0224		13,219,331	540	0.6343		
5		0.0001		580	0.8378		
140	0.0337		12,301,425	Ruptured.			
180	0.0477		11,174,068	580	0.8653		
200	0.0552		10,728,725	680	1.46		
5		0.0095		720	1.74		
240	0.0674		10,540,763	800	2.39		
280	0.0910		9,111,146	840	2.85		
320	0.1176			860	3.23		
360	0.1663						
400	0.2057						
5		0.1114					
440	0.2883						

Supports slid out. Bar bent.

Breaking load, P=860 pounds.

Modulus of rupture, $R=\frac{3}{2}\frac{Pl}{bd^2}=30,621$.

TABLE CCII.—BAR OF CAST COPPER.

Original mark: No. 56.—Material: Copper cast in iron mold.—Dimensions: $l=22''$. $b=0.972''$. $d=0.955''$.

Load.	Deflection.	Set.	Modulus of elasticity.	Load.	Deflection.	Set.	Modulus of elasticity.
40	0.0088		14,293,526	480	1.30		
80	0.0191		13,170,088	500	1.47		
100	0.0261		12,048,347	520	1.65		
5		0.0048		540	1.81		
140	0.0462		9,739,155	560	2.01		
180	0.0606		9,339,672	580	2.21		
200	0.0861		7,303,964	600	2.41		
5		0.0402		620	2.66		
240	0.1392			640	3.51		
280	0.2247						
320	0.3628						
360	0.5397						
400	0.7752						
5		0.6702					
440	1.01						

Supports slid out. Bar bent.

Breaking load, P=640 pounds.

Modulus of rupture, $R=\frac{3}{2}\frac{Pl}{bd^2}=23,824$.

RECORD OF TESTS BY TRANSVERSE STRESS—Continued.

MECHANICAL LABORATORY, DEPARTMENT OF ENGINEERING, STEVENS INSTITUTE OF TECHNOLOGY.

TABLE CCIII.—BAR OF CAST COPPER.

Original mark: No. 57.—**Material:** Lake Superior copper cast in iron mold.—**Dimensions:** Length between supports, $l=22''$. $b=1.010''$. $d=1.010''$.

Load.	Deflection. Δ	Set.	Modulus of elasticity. $\frac{Pl^3}{4\Delta bd^3}$
Pounds.	*Inches.*	*Inches.*	
10	0.0068		
20	0.0099		5,168,758
40	0.0148		6,914,825
80	0.0232		8,822,534
100	0.0280		9,137,625
3		0.0084	
150	0.0401		9,036,856
200	0.0538		9,511,283
250	0.0680		9,406,380
300	0.0889		8,633,976
350	0.1193		7,506,180
400	0.1670		6,128,228
3		0.0812	
420	0.1908		
450	0.2798		
500	0.4910		
520	0.5898		
540	0.7110		
580	0.9913		
600	1.1248		
3		0.9840	
Resistance increased in 15 minutes to 10 pounds.			
3		0.9832	
Decrease of set in 15 minutes.		0.0008	
600	1.1483		
620	1.22		
640	1.40		
680	1.75		
720	2.10		
760	2.48		
800	3.22		
820	3.77		

Bent without breaking.
Breaking load, $P=820$ pounds.
Modulus of rupture, $R=\frac{3}{2}\frac{Pl}{bd^2}=26,271$.

TABLE CCIV.—BAR OF CAST TIN.

Original mark: No. 58.—**Material:** Queensland tin cast in iron mold.—**Dimensions:** $l=22''$. $b=1.038''$. $d=1.023''$.

10	0.0082		
20	0.0118		5,754,991
3		0.0009	
10	0.0087		
20	0.0129		
30	0.0173		5,310,020
40	0.0241		5,635,593
50	0.0333		3,596,764
3		0.0126	
60	0.0502		
70	0.0600		
80	0.0859		
90	0.1416		
100	0.2109		
3		0.1763	
100	0.2415		
Resistance decreased in 1 minute to 70 pounds.			
Resistance decreased in 3 minutes to 62 pounds.			
Resistance decreased in 8 minutes to 56 pounds.			
100	0.3033		
110	0.3827		
120	0.6403		
130	0.8091		
130 Cont'd 1 min.	1.07		
140	1.36		
150	Ran pressure-screw down slowly till deflection was more than 3 inches; the scale-beam vibrating all the time about 150 pounds.		

Bent without breaking.
Breaking load, $P=150$ pounds.
Modulus of rupture, $R=\frac{3}{2}\frac{Pl}{bd^2}=4,559$.

RECORD OF TESTS BY TENSILE STRESS.

MECHANICAL LABORATORY, DEPARTMENT OF ENGINEERING, STEVENS INSTITUTE OF TECHNOLOGY.

TABLE CCV.—CAST COPPER (FLUXED WITH FLUOR SPAR).

Original mark: No, 51 A.—**Material:** Copper cast in hot iron mold, fluxed with fluor spar.—Dimensions: Length, 6.12″. Diameter, 0.798″.

Load per square inch.	Elongation in 6.12 inches.	Set.	Elongation in parts of original length.
Inches.	*Inches.*	*Inches.*	
6,980	0.01		.0016
8,480	0.02		.0033
9,840	0.03		.0049
10,700	0.04		.0065
11,560	0.06		.0098
11,800	0.07		.0114
12,310	0.09		.0147
13,560	0.12		.0196
14,440	0.16		.0261
14,540	Broke 1 inch from C end.		

Fractured section elliptical.
Diameters, 0.770 and 0.0780 inch.
Tenacity per square inch, original section, 14,540 pounds.
Tenacity per square inch, fractured section, 15,412 pounds.

RECORD OF TESTS BY TENSILE STRESS—Continued.

Mechanical Laboratory, Department of Engineering, Stevens Institute of Technology.

TABLE CCVI.—CAST COPPER (FLUXED WITH FLUOR SPAR).

Original mark: No. 51 B.—**Material:** Copper cast in hot iron mold fluxed with fluor spar.—**Dimensions:** Length, 6.19″. Diameter, 0.798″.

Load per square inch.	Elongation in 6.19 inches.	Set.	Elongation in parts of original length.
Pounds.	*Inches.*	*Inches.*	
8, 000	0. 01		. 0016
9, 800	0. 02		. 0032
10, 000	0. 03		. 0048
11, 400	0. 07		. 0113
12, 400	0. 11		. 0178
15, 100	0. 17		. 0275
16, 200	0. 23		. 0372
17, 040	0. 26		. 0258
18, 000	0. 30		. 0485
19, 400	0. 36		. 0581
20, 000	0. 40		. 0646
0		0. 40	
20, 400	0. 44		. 0710
20, 440	0. 46		. 0743

Broke at D end.

Diameter of fractured section, 0.763 inch.

Tenacity per square inch, original section, 20,440 pounds.

Tenacity per square inch, fractured section, 22,353 pounds.

The following measurements were made of the diameter of the piece after breaking:

	Inches.
At fractured section	0. 763
½ inch from fractured section	0. 765
1 inch from fractured section	0. 766
2 inches from fractured section	0. 766
3 inches from fractured section	0. 765
4 inches from fractured section	0. 766
4½ inches from fractured section	0. 767
5 inches from fractured section	0. 768
6 inches from fractured section	0. 768
6½ inches from fractured section	0. 774

TABLE CCVII.—CAST COPPER.

Original mark: No. 52 A.—**Material:** Copper cast in iron mold.—**Dimensions:** Length, 5.95″. Diameter, 0.798″.

Load per square inch.	Elongation in 5.95 inches.	Set.	Elongation in parts of original length.
Pounds.	*Inches.*	*Inches.*	
800	0. 0008		. 0001
1, 800	0. 0012		. 0002
2, 800	0. 0023		. 0004
3, 700	0. 0037		. 0006
200		0. 0002	
4, 000	0. 0042		. 0007
4, 800	0. 0048		. 0008
200		0. 0004	
6, 100	0. 0066		. 0011
7, 100	0. 0080		. 0013
7, 700	0. 0098		. 0016
200		0. 0028	
8, 000	0. 0102		. 0017
8, 950	0. 0129		. 0022
9, 800	0. 0158		. 0027
200		0. 0084	
10, 500	0. 0195		. 0033
11, 700	0. 0272		. 0046
12, 000	0. 0315		. 0053
200		0. 0232	
12, 400	0. 0373		. 0063
13, 450	0. 0439		. 0074
200		0. 0353	
14, 000	0. 0510		. 0086
14, 850	0. 0628		. 0106
16, 000	0. 0853		. 0143
200		0. 0743	
16, 940	0. 0953		. 0160

Broke.

Diameter of fractured section, 0.775 inch.

Tenacity per square inch, original section, 16,940 pounds.

Tenacity per square inch, fractured section, 17,956 pounds.

RECORD OF TESTS BY TENSILE STRESS—Continued.

MECHANICAL LABORATORY, DEPARTMENT OF ENGINEERING, STEVENS INSTITUTE OF TECHNOLOGY.

TABLE CCVIII.—CAST COPPER.

Original mark: No. 52 B.—**Material**: Copper cast in iron mold.—**Dimensions**: Length, 5″. Diameter, 0.798″.

Load per square inch.	Elongation in 5 inches.	Set.	Elongation in parts of original length.	Load per square inch.	Elongation in 5 inches.	Set.	Elongation in parts of original length.
Pounds.	*Inches.*	*Inches.*		*Pounds.*	*Inches.*	*Inches.*	
1,200	0.0018	....	.0004	17,600	0.2857	....	.0571
2,000	0.0024	....	.0005	18,400	0.3236	....	.6047
4,000	0.0028	....	.0006	200	....	0.3122	....
8,000	0.0050	....	.0010	19,200	0.3752	....	.0750
8,800	0.0068	....	.0014	20,000	0.4088	....	.0817
9,600	0.0100	....	.0020	20,800	0.4402	....	.0880
10,400	0.0180	....	.0036	21,200	0.4582	....	.0916
11,200	0.0284	....	.0057	21,600	Broke in middle.		
12,000	0.0467	....	.0093				
12,800	0.0658	....	.0132				
13,600	0.0932	....	.0187				
14,400	0.1250	....	.0250				
15,200	0.1607	....	.0321				
16,000	0.1984	....	.0397				
16,800	0.2347	....	.0469				

Fractured section elliptical. Diameters, 0.715 and 0.707 inch.

Tenacity per square inch, original section, 21,600 pounds.

Tenacity per square inch, fractured section, 27,204 pounds.

TABLE CCIX.—CAST COPPER.

Original mark: No. 53 A.—**Material**: Copper cast in iron mold.—**Dimensions**: Length, 5″. Diameter 0.798″.

Load per square inch.	Elongation in 5 inches.	Set.	Elongation in parts of original length.
Pounds.	*Inches.*	*Inches.*	
12,800	0.0135	....	.0027
13,600	0.0167	....	.0033
14,400	0.0225	....	.0045
15,200	0.0310	....	.0062
16,000	0.0421	....	.0084
16,800	0.0535	....	.0107
17,600	0.0664	....	.0133
18,000	0.0744	....	.0149
18,400	0.0818	....	.0163
18,800	Broke 1 inch from A end.		

Diameter of fractured section, 0.780 inch.

Fractured surface spongy, full of blow-holes.

Tenacity per square inch, original section, 18,800 pounds.

Tenacity per square inch, fractured section, 19,673 pounds.

TABLE CCX.—CAST COPPER.

Original mark: No. 53 B.—**Material**: Copper cast in iron mold.—**Dimensions**: Length, 5″. Diameter, 0.798″.

Broke at 9,200 pounds per square inch. The piece bent while it was being strained so that the elongations could not be determined.

The piece was spongy and full of blow-holes throughout.

RECORD OF TESTS BY TENSILE STRESS—Continued.

MECHANICAL LABORATORY, DEPARTMENT OF ENGINEERING, STEVENS INSTITUTE OF TECHNOLOGY.

TABLE CCXI.—OF CAST COPPER.

Original mark: No. 57 A.—**Material:** Copper cast in iron mold.—**Dimensions:** Length, 5″. Diameter, 0.798″.

Load per square inch.	Elongation in 5 inches.	Set.	Elongation in parts of original length.
Pounds.	*Inches.*	*Inches.*	
1,000	0.0009	....	.0002
2,000	0.0038	....	.0008
3,000	0.0066	....	.0013
4,000	0.0089	....	.0018
5,000	0.0113	....	.0023
6,000	0.0137	....	.0027
7,000	0.0168	....	.0034
8,000	0.0205	....	.0041
240	....	0.0089	....
9,000	0.0234	....	.0047
10,000	0.0279	....	.0056
11,000	0.0335	....	.0067
12,000	0.0402	....	.0080
240	....	0.0324	....
13,000	0.0492	....	.0098
14,000	0.0627	....	.0125
15,000	0.0798	....	.0160
16,000	0.1041	....	.0208
240	....	0.0964	....
17,000	0.1277	....	.0255
18,000	0.1507	....	.0301
19,000	0.1806	....	.0361
20,000	0.2122	....	.0424
240	....	0.2009	....
21,000	0.2455	....	.0491
22,000	0.2828	....	.0566
23,000	0.3205	....	.0641
24,000	0.3686	....	.0737
240	....	0.3551	....
25,000	0.4180	....	.0836
26,000	0.4670	....	.0934

Broke in middle.

Diameter of fractured section, 0.738 inch.

One elliptical blowhole in fractured surface. Diameters, 0.48 and 0.08 inch.

Tenacity per square inch, original section, 26,000 pounds.

Tenacity per square inch, fractured section, 30,398 pounds.

TABLE CCXII.—CAST COPPER.

Original mark: No. 57 B.—**Material:** Copper cast in iron mold.—**Dimensions:** Length, 5″. Diameter, 0.798″.

Load per square inch.	Elongation in 5 inches.	Set.	Elongation in parts of original length.
Pounds.	*Inches.*	*Inches.*	
1,000	0.0004	....	.0001
2,000	0.0032	....	.0006
3,000	0.0064	....	.0013
4,000	0.0093	....	.0019
5,000	0.0116	....	.0023
6,000	0.0144	....	.0029
7,000	0.0170	....	.0034
8,000	0.0201	....	.0040
240	....	0.0037	....
9,000	0.0227	....	.0045
10,000	0.0263	....	.0053
11,000	0.0321	....	.0064
12,000	0.0371	....	.0074
240	....	0.0253	....
13,000	0.0428	....	.0086
14,000	0.0485	....	.0097
15,000	0.0554	....	.0111
16,000	0.0652	....	.0130
240	....	0.0583	....
17,000	0.0779	....	.0156
18,000	0.0951	....	.0190
19,000	0.1142	....	.0228
22,000	0.1388	....	.0278
240	....	0.1317	....
21,000	0.1702	....	.0340
22,000	0.2028	....	.0406
23,000	0.2444	....	.0489
24,000	0.3020	....	.0604
240	....	0.2983	....
25,000	0.3585	....	.0717
26,000	Measuring apparatus slipped.		
29,820	Broke 2 inches from B end.		

Diameter of fractured section, 0.724 inch.

Tenacity per square inch, original section, 29,820 pounds.

Tenacity per square inch, fractured section, 36,217 pounds.

RECORD OF TESTS BY TENSILE STRESS—Continued.

Mechanical Laboratory, Department of Engineering, Stevens Institute of Technology.

TABLE CCXIII.—QUEENSLAND TIN, CAST.

Original mark: No. 58 A.—Material: tin cast in iron mold.—Dimensions: Length, 5″. Diameter, 0.798″.

Load per square inch.	Elongation in 5 inches.	Set.	Elongation in parts of original length.
Pounds.	*Inches.*	*Inches.*	
400	0.0002		.00004
600	0.0027		.0005
800	0.0081		.0016
1,000	0.0175		.0035
240		0.0159	
1,200	0.0309		.0062
1,400	0.0433		.0086
1,600	0.0517		.0103
1,800	0.0630		.0126
2,000	0.0745		.0149
240		0.0756	
2,000	0.0860		.0172

2,000 pounds per square inch kept constant for 14 minutes, elongation increasing as follows:

Load per square inch.	Elongation in 5 inches.	Set.	Elongation in parts of original length.
Minutes.	*Inches.*	*Pounds.*	
1	0.1070		
2	0.1156		
3	0.1298		
4	0.1437		
5	0.1580		
6	0.1709		
7	0.1861		
8	0.1997		
9	0.2176		
10	0.2328		
11	0.2490		
12	0.2687		
13	0.2929		
14	0.3311		

Resistance reduced to 1,700 pounds per square inch, and a crack was observed on one side.

Load per square inch.	Elongation in 5 inches.	Set.	Elongation in parts of original length.
1,700 lbs.	0.3610		.0722
1 min.	0.4315		.0863

Resistance decreased gradually, and piece broke 2 inches from A end.

The fractured surface had an irregular boundary nearly elliptical; two diameters measured 0.580 and 0.685 inch.

Tensile strength per square inch, original section, under slow strain, 2,000 pounds.

Total time of test, 30 minutes.

TABLE CCXIV.—QUEENSLAND TIN, CAST.

Original mark: No. 58 B.—Material: tin cast in iron mold.—Dimensions: Length, 5″. Diameter, 0.798″.

Load per square inch.	Elongation in 5 inches.	Set.	Elongation in parts of original length.
Pounds.	*Inches.*	*Inches.*	
400	0.0005		.0001
600	0.0029		.0006
800	0.0051		.0010
1,000	0.0108		.0022
1,200	0.0184		.0037
1,400	0.0293		.0059
1,600	0.0394		.0079
1,800	0.0484		.0097
2,000	0.0566		.0113
240		0.0557	
Pounds.	*Inches.*	*Inches.*	
2,000	0.0631		.0126

Stress kept constant for 2 minutes.

Load per square inch.	Elongation in 5 inches.	Set.	Elongation in parts of original length.
1 min.	0.0724		.0145
2 min.	0.0821		.0161

Increased stress rapidly for 1 minute, and piece broke at 3,520 pounds per square inch.

Total time of test, 8 minutes.

Diameter of fractured section, 0.542 inch.

Tensile strength per square inch, original section, under rapid strain, 8,520 pounds.

TESTS BY TORSIONAL STRESS OF EXTRA PIECES OF COPPER AND TIN.

CALCULATED FROM THE AUTOGRAPHIC STRAIN DIAGRAMS.

MECHANICAL LABORATORY, DEPARTMENT OF ENGINEERING, STEVENS INSTITUTE OF TECHNOLOGY.

TABLE CCXV.—LAKE SUPERIOR COPPER.

No.	Area of diagram.	Angle of torsion.	Maximum ordinate.	Ordinate at elastic limit.	Maximum torsional moment.	Torsional moment at elastic limit.	Extension of exterior fiber.	Resilience.
	Sq. inches.	°	*Inches.*	*Inches.*	*Ft. pounds.*	*Ft. pounds.*		*Ft. pounds.*
51 A...	6.90	128	0.65	0.18	87.19	32.00	0.2196	165.65
B...	21.18	135	1.90	0.70	134.38	52.94	0.2418	263.58
C...	10.58	168.5	0.80	0.35	104.81	51.96	0.3582	248.74
D...	5.29	113	0.85	0.20	110.68	34.34	0.1747	129.81
52 A...	13.16	185	1.05	0.15	134.17	28.47	0.4206	304.75
B...	8.75	109	0.96	0.42	100.78	43.64	0.1634	199.97
D...	15.63	170	1.20	0.27	124.97	31.22	0.3637	351.53
53 A...	7.58	82	1.15	0.35	119.93	39.28	0.0954	170.88
B...	2.72	47	0.80	0.35	84.65	39.28	0.0323	64.65
C...	2.70	40	0.80	0.40	84.65	44.32	0.0235	62.91
D...	2.70	39	0.85	0.40	89.69	44.32	0.0224	62.72
57 A...	4.29	72	0.70	0.20	74.57	24.16	0.0743	80.49
B...	15.44	160	1.15	0.50	119.93	54.41	0.3272	282.76
C...	7.84	98	0.95	0.40	99.77	44.32	0.1339	144.75
D...	9.35	115	1.00	0.30	104.81	34.24	0.1804	172.49

TABLE CCXVI.—QUEENSLAND TIN.

58 B...	34.78	619	0.65	0.20	11.73	4.08	2.5211	176.21
C...	65.55	818	0.95	0.25	16.84	4.93	3.5722	291.04
D...	28.00	637	0.60	0.20	10.88	4.08	2.6154	158.20

RECORD OF TESTS BY COMPRESSIVE STRESS.

TABLE CCXVII.—ALLOY OF COPPER AND TIN.

Original mark: No. 31.—**Material:** Alloy.—**Original mixture:** 97.5 Cu, 2.5 Sn.—**Analysis:** 99.09 Cu, 0.87 Sn.—**Dimensions:** Length, 2″. Diameter, 0.625″.

Load.	Compression.	Load per square inch.	Compression in parts of original length.	Load.	Compression.	Load per square inch.	Compression in parts of original length.
Pounds.	*Inches.*	*Pounds.*		*Pounds.*	*Inches.*	*Pounds.*	
150	.0000	....	....	16,000	.3951	52,152	.1975
2,000	.0018	6,519	.0009	18,000	.5176	58,671	.2588
4,000	.0093	13,028	.0046	20,000	.6156	65,188	.3078
6,000	.0302	19,557	.0151	22,000	.7266	71,709	.3683
8,000	.0609	26,075	.0305	24,000	.8483	78,228	.4242
10,000	.1077	32,595	.0539	25,000	.8801*	81,485	.4400
12,000	.1662	39,114	.0831				
14,000	.2601	45,633	.1300				

* Wedge cracked off at the top.

CCXVIII.—ALLOY OF COPPER AND TIN,

Original mark: No. 32.—**Material:** Alloy.—**Original mixture:** 92.5 Cu, 7.5 Sn.—**Analysis:** 94.11 Cu, 5.43 Sn.—**Dimensions:** Length, 2″. Diameter, 0.625″.

150	.0000	....	....	22,000	.4584	71,709	.2292
2,000	.0000	6,519	....	24,000	.5151	78,228	.2575
4,000	.0000	13,038	....	26,000	.5778	84,747	.2889
6,000	.0002	19,557	.0001	28,000	.6393	91,266	.3197
8,000	.0108	26,075	.0054	30,000	.7000	97,780	.3500
10,000	.0511	32,595	.0255	32,000	.7499	104,303	.3749
12,000	.1219	39,114	.0609	34,000	.8033	110,822	.4016
14,000	.1937	45,633	.0968	36,000	.8447	117,341	.4223
16,000	.2648	52,152	.1324	38,000	.8918	123,860	.4459
18,000	.3310	58,671	.1655	40,000	.9330	130,379	.4665
20,000	.3951	65,188	.1975				

RECORD OF TESTS BY COMPRESSIVE STRESS—Continued.

MECHANICAL LABORATORY, DEPARTMENT OF ENGINEERING, STEVENS INSTITUTE OF TECHNOLOGY.

TABLE CCXIX.—ALLOY OF COPPER AND TIN.

Original mark: No. 33.—Material: Alloy.—Original mixture: 87.5 Cu, 12.5 Sn.—Analysis: 88.40 Cu, 11.59 Sn.—Dimensions: Length, 2″. Diameter, 0.625″.

Load.	Compression.	Load per square inch.	Compression in parts of original length.	Load.	Compression.	Load per square inch.	Compression in parts of original length.
Pounds.	*Inches.*	*Pounds.*		*Pounds.*	*Inches.*	*Pounds.*	
150	.0000	....	....	24,000	.3234	78,228	.1617
4,000	.0014	13,038	.0007	26,000	.3575	84,747	.1783
6,000	.0058	19,557	.0029	28,000	.4019	91,266	.2009
8,000	.0170	26,075	.0085	30,000	.4412	97,785	.2206
10,000	.0374	32,595	.0187	32,000	.4815	104,303	.2407
12,000	.0711	39,114	.0355	34,000	.5171	110,822	.2585
14,000	.1166	45,633	.0553	36,000	.5534	117,341	.2767
16,000	.1636	52,152	.0818	38,000	.5905	123,860	.2952
18,000	.2102	58,671	.1051	40,000	.6234	130,379	.3117
20,000	.2564	65,188	.1282	42,000	.6611	136,898	.3305
22,000	.2991	71,709	.1495	44,000	.6911	143,417	.3455

TABLE CCXX.—ALLOY OF COPPER AND TIN.

Original mark: No. 34.—Material: Alloy.—Original mixture: 82.5 Cu, 17.5 Sn.—Analysis: 82.72 Cu, 17.33 Sn.—Dimensions: Length, 2″. Diameter, 0.625″.

150	.0000	....	....	32,000	.2111	104,303	.1055
10,000	.0005	32,595	.00025	34,000	.2381	110,822	.1190
12,000	.0044	39,114	.0022	36,000	.2704	117,341	.1352
14,000	.0107	45,633	.0053	38,000	.3088	123,860	.1544
16,000	.0174	52,152	.0087	40,000	.3396	130,379	.1698
18,000	.0268	58,671	.0134	42,000	.3821	136,898	.1910
20,000	.0408	65,188	.0204	44,000	(*)	143,417	....
22,000	.0628	71,709	.0314				
24,000	.0872	78,228	.0436				
26,000	.1123	84,747	.0561				
28,000	.1464	91,266	.0732				
30,000	.1766	97,785	.0883				

* A wedge-shaped piece slid off at the top, and a piece cracked off at the bottom; it was also cracked badly at the middle.

TABLE CCXXI.—ALLOY OF COPPER AND TIN.

Original mark: No. 35.—Material: Alloy.—Original mixture: 77.5 Cu, 22.5 Sn.—Analysis: 77.56 Cu, 22.25 Sn.—Dimensions: Length, 2″. Diameter, 0.625″.

150	.0000	....	....	34,000	.0447	110,822	.0223
14,000	.0009	45,633	.00045	36,000	.0614	117,341	.0307
16,000	.0029	52,152	.00145	38,000	.0807	123,860	.0403
18,000	.0045	58,671	.00225	40,000	.1006	130,379	.0503
20.000	.0070	65,188	.0035	42,000	.1212	136,898	.0606
22,000	.0092	71,709	.0046	44,000	.1537	143,417	.0768
24,000	.0120	78,228	.0060	46,000	.2027	149,932	.1013
26,000	.0155	84,747	.0077				
28,000	.0190	91,266	.0095				
30,000	.0260	97,785	.0130				
32,000	.0342	104,303	.0171				

The specimen was cracked a little at the top. Had to stop on account of the capacity of the machine.

TABLE CXXII.—ALLOY OF COPPER AND TIN.

Original mark: No. 43.—Material: Alloy.—Original mixture: 37.5 Cu, 62.5 Sn.—Analysis: 37.10 Cu, 62.9 Sn.—Dimensions: Length, 2″. Diameter, 0.625″.

Load.	Compression.	Load per square inch.	Compression in parts of original length.
Pounds.	*Inches.*	*Pounds.*	
150	.0000	....	....
2,000	.0051	6,519	.0025
4,000	(*)	....	....

* The bottom of the specimen all crumbled away.

RECORD OF TESTS BY COMPRESSIVE STRESS—Continued.

MECHANICAL LABORATORY, DEPARTMENT OF ENGINEERING, STEVENS INSTITUTE OF TECHNOLOGY.

TABLE CCXXIII.—ALLOY OF COPPER AND TIN.

Original mark: No. 44.—**Material:** Alloy.—**Original mixture:** 32.5 Cu, 62.5 Sn.—**Analysis:** 30.76 Cu, 69.19 Sn.—**Dimensions:** Length, 2″. Diameter. 0.625″.

Load.	Compression.	Load per square inch.	Compression in parts of original length.	Broke by a wedge-shaped piece sliding off of the top; the bottom cracked.
Pounds.	*Inches.*	*Pounds.*		
150	.0000	....	....	
3,000	.0010	9,778	.0005	
4,000	.0081	13,038	.0040	
5,000	Lifted the beam.	16,297	....	

TABLE CCXXIV.—ALLOY OF COPPER AND TIN.

Original mark: No. 45.—**Material:** Alloy.—**Original mixture:** 27.5 Cu, 72.5 Sn.—**Analysis:** 26.62 Cu, 73.18 Sn.—**Dimensions:** Length, 2″. Diameter, 0.625″.

150	.0000	....	....	Crushed by having a wedge-shaped piece slide out of the middle of the specimen.
2,000	.0019	6,519	.00095	
3,000	.0062	9,778	.0031	
4,000	.0182	13,038	.0091	
5,000	Lifted the beam.	16,297	....	

TABLE CCXXV.—ALLOY OF COPPER AND TIN.

Original mark: No. 46.—**Material:** Alloy.—**Original mixture:** 22.5 Cu, 77.5 Sn.—**Analysis:** 22.10 Cu, 77.58 Sn.—**Dimensions:** Length, 2″. Diameter, 0.625″.

150	.0000	....	....	Broke by wedge-shaped piece sliding off the specimen near the bottom.
1,000	.0028	3,259	.0014	
2,000	.0057	6,519	.0028	
3,000	.0103	9,778	.0051	
4,000	.0227	13,038	.0118	
5,000	Lifted the beam.	16,297	....	

TABLE CCXXVI.—ALLOY OF COPPER AND TIN.

Original mark: No. 47.—**Material:** Alloy.—**Original mixture:** 17.5 Cu, 82.5 Sn.—**Analysis:** 16.70 Cu, 83.23 Sn.—**Dimensions:** Length, 2″. Diameter, 0.625″.

150	.0000	....	....	The specimen crushed by having a wedge-shaped piece slide out at the middle.
1,000	.0006	3,259	.0003	
2,000	.0051	6,519	.0025	
3,000	Lifted the beam.	9,778	....	

RECORD OF TESTS BY COMPRESSIVE STRESS—Continued.

MECHANICAL LABORATORY, DEPARTMENT OF ENGINEERING, STEVENS INSTITUTE OF TECHNOLOGY.

TABLE CCXXVII.—ALLOY OF COPPER AND TIN.

Original mark: No. 48.—**Material:** Alloy.—**Original mixture:** 12.5 Cu, 87.5 Sn.—**Analysis:** 11.68 Cu, 88.25 Sn.—**Dimensions:** Length, 2″. Diameter, 0.625″.

Load.	Compression.	Load per square inch.	Compression in parts of original length.	The specimen was broken by having a wedge-shaped piece slide off at the top and at the bottom.
Pounds.	*Inches.*	*Pounds.*		
150	.0000	....	....	
1,000	.0009	3,259	.00045	
2,000	.0176	6,519	.0088	
3,000	.0611	9,778	.0305	
4,000	Lifted the beam.	....	....	

TABLE CCXXVIII.—CAST COPPER.

Original mark: No. 51 B.—**Material:** Cast copper.—**Dimensions:** Length, 2″. Diameter, 0.625″.

Load.	Compression.	Load per square inch.	Compression in parts of original length.	Load.	Compression.	Load per square inch.	Compression in parts of original length.
Pounds.	*Inches.*	*Pounds.*		*Pounds.*	*Inches.*	*Pounds.*	
150	.0000	....	....	20,000	.6461	65,188	.3230
4,000	.0006	13,038	.0003	22,000	.7295	71,709	.3647
6,000	.0089	19,557	.0044	24,000	.7936	78,228	.3968
8,000	.0573	26,075	.0286	26,000	.8619	84,747	.4309
10,000	.1560	32,595	.0780	28,000	.9258	91,266	.4679
12,000	.2568	39,114	.1284	30,000	.9783	97,785	.4891
14,000	.3602	45,633	.1801	32,000	1.0308	104,303	.5154
16,000	.4489	52,152	.2244	Specimen did not show any cracks, but merely flattened down.			
18,000	.5511	58,671	.2756				

TABLE CCXXIX.—CAST COPPER.

Original mark: No. 52.—**Material:** Cast copper.—**Dimensions:** Length, 2″. Diameter, 0.625″.

150	0.0000	....	....	18,000	.5770	58,671	.2885
6,000	.0041	19,557	.0020	20,000	.6815	65,188	.3408
8,000	.0305	26,075	.0153	22,000	.7665	71,709	.3833
10,000	.1372	32,595	.0680	24,000	.7925	78,228	.3962
12,000	.2375	39,114	.1186	26,000	.9025	84,747	.4512
14,000	.3547	45,633	.1773	28,000	.9628	91,266	.4814
16,000	.4737	52,152	.2368				

TABLE CCXXX.—CAST COPPER.

Original mark: No. 53.—**Material:** Cast copper.—**Dimensions:** Length, 2″. Diameter, 0.625″.

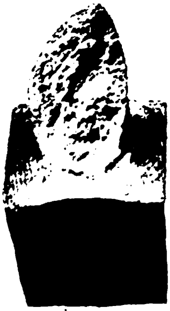
150	.0000	....	....	18,000	.3194	58,671	.1597
4,000	.0060	13,038	.0030	20,000	.4029	65,188	.2014
6,000	.0148	19,557	.0074	22,000	.4991	71,709	.2495
8,000	.0485	26,075	.0242	24,000	.5893	78,228	.2946
10,000	.0851	32,595	.0425	26,000	.6853	84,747	.3426
12,000	.1285	39,114	.0642	28,000	.7542	91,266	.3871
14,000	.1777	45,633	.0888	30,000	.8244	97,785	.4122
16,000	.2411	52,152	.1205	Flattened down without showing any cracks.			

PHOTOGRAPHS OF FRACTURES

OF

COPPER-TIN ALLOYS.

PLATE No. 1.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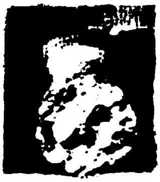
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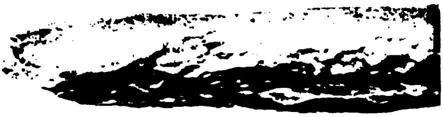
Copper.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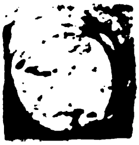
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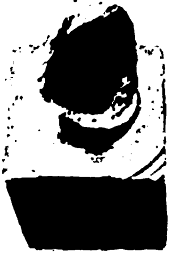
27B.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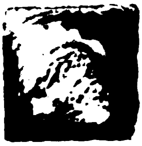
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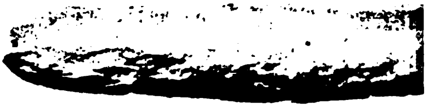
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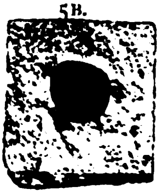
Tin.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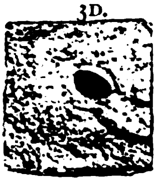
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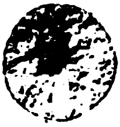
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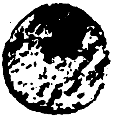
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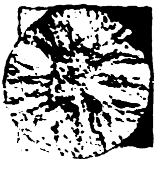
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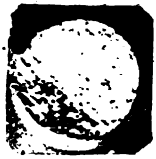
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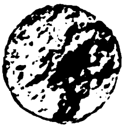
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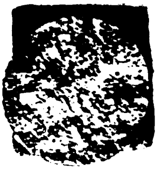
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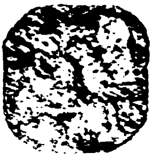
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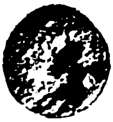
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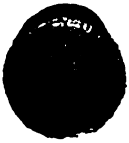
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Heliotype Printing Co., 211 Tremont Street, Boston.

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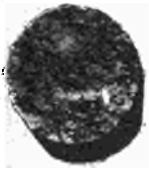
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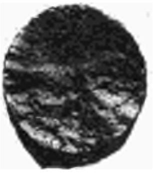
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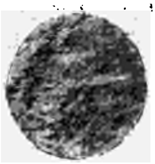
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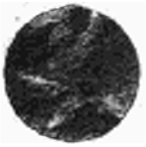
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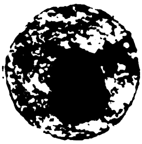
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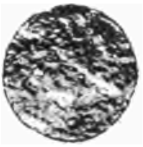
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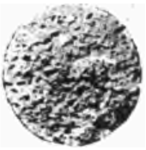
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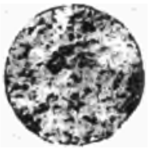
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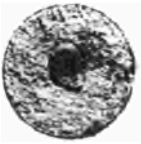
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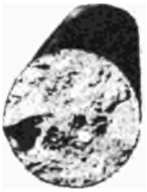
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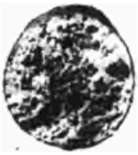
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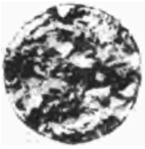
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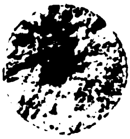
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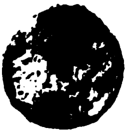
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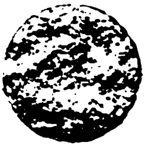
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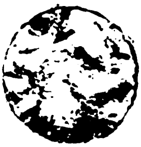
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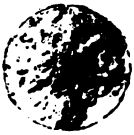
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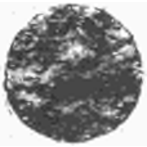
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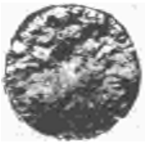
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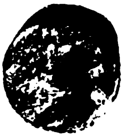
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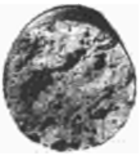
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Heliotype Printing Co., 211 Tremont Street, Boston.

PLATE No. 3.

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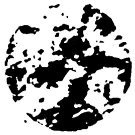
28B.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29B.

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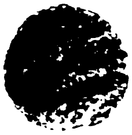
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10A.

25A.

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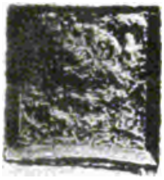
Tin.

15A.

19C.

19.

Heliotype Printing Co., 211 Tremont Street, Boston.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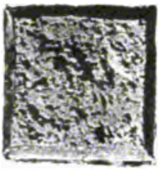
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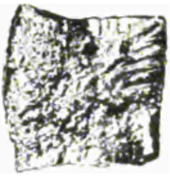
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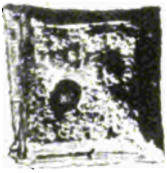
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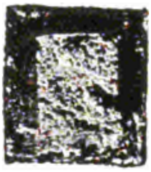
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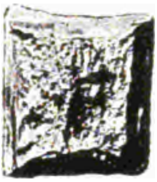
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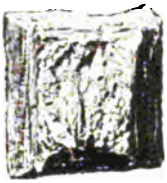
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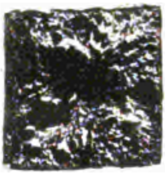
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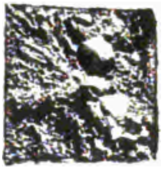
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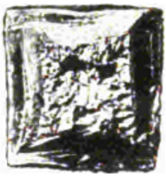
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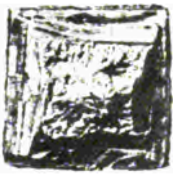
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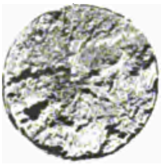
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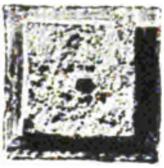
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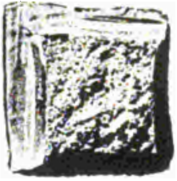
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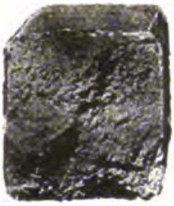
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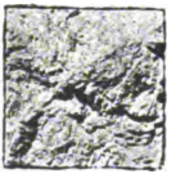
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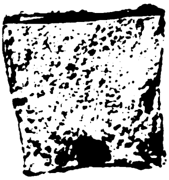
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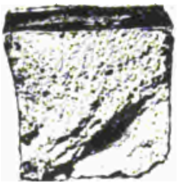
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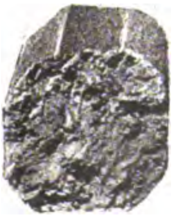
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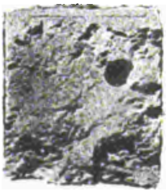
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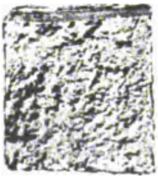
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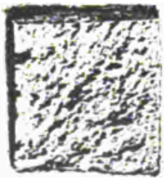
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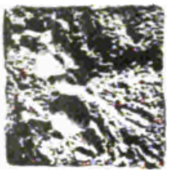
Heliotype Printing Co., 211 Tremont Street, Boston.

PLATE No. 5.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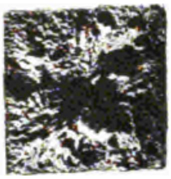
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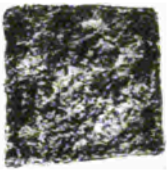
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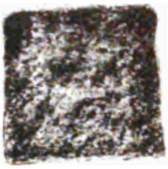
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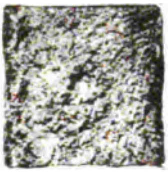
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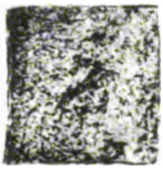
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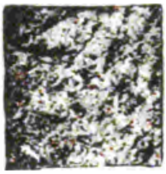
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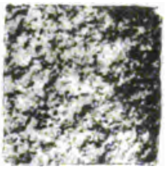
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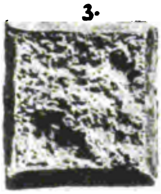
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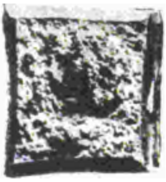
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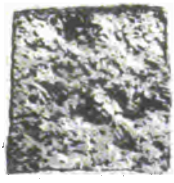
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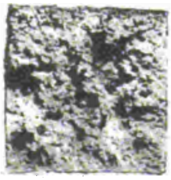
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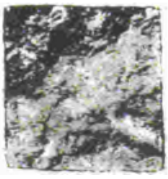
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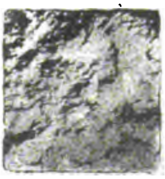
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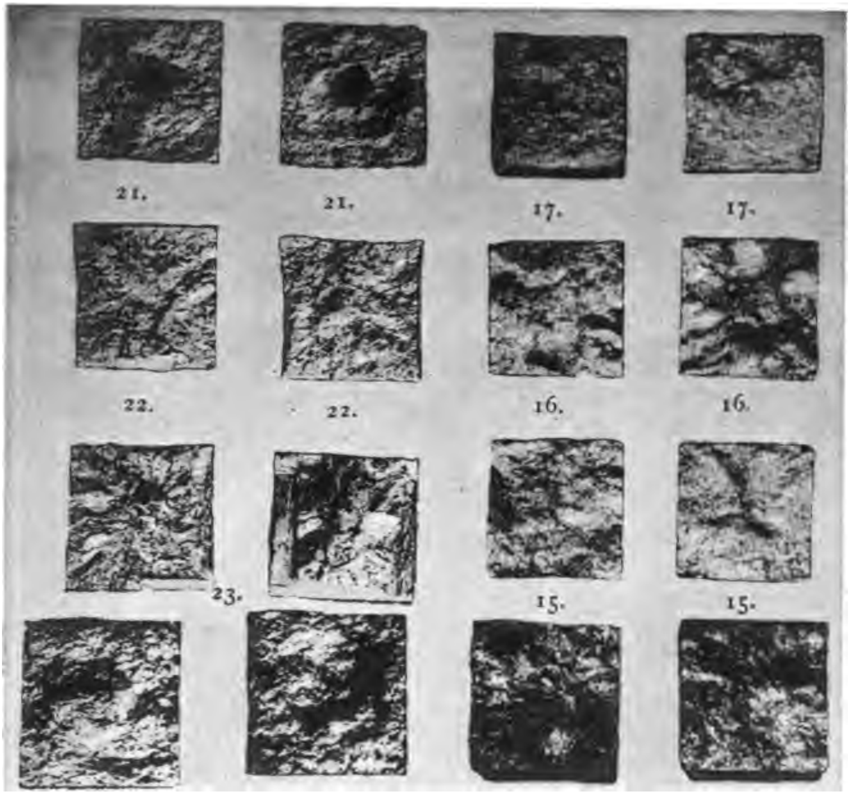
Heliotype Printing Co., 211 Tremont Street, Boston.



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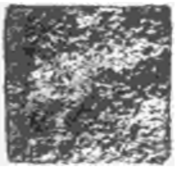

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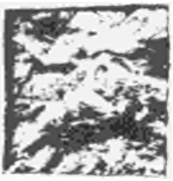

20.

Heliotype Printing Co., 211 Tremont Street, Boston.

PLATES I–XXI.

GRAPHICAL REPRESENTATIONS

OF THE

PROPERTIES OF COPPER-TIN ALLOYS.

- PLATE I.—Tests by Transverse Stress.
  - Modulus of Rupture in Pounds.
  - Modulus at Elastic Limit in Pounds
  - Total Deflection in Inches.
- PLATE II.—Tests by Tensile Stress.
  - Tensile Strength in Pounds per Square Inch of Original Section.
  - Tensile Strength in Pounds per Square Inch of Fractured Section.
  - Tensile Strength at the Elastic Limit.
  - Total Elongation in Parts of Original Length.
- PLATE III.—Tests by Torsional Stress.
  - Maximum Torsional Moment in Foot-Pounds.
  - Torsional Moment at Elastic Limit in Foot-Pounds.
  - Resilience in Foot-Pounds.
  - Extension of Exterior Fiber in Parts of Original Length.
- PLATE IV.—Tests by Compressive Stress.
  - Crushing Strength in Pounds per Square Inch.
  - Total Compression at Maximum Load in Parts of Original Length.
- PLATE V.—Mean Specific Gravity.
- PLATE VI.—Variation of Analyses from Original Compositions.
- PLATE VII.—Comparison of Transverse, Tensile, Torsional, and Compressive Resistances.
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  - Tensile Strength in Pounds per Square Inch of Original Section.
  - Crushing Strength in Pounds per Square Inch.
  - Maximum Torsional Moment in Foot-Pounds.
- PLATE VIII.—Comparison of Transverse, Tensile, and Torsional Resistances [Scale Enlarged].
  - Transverse Modulus of Rupture in Pounds.
  - Tensile Strength per Square Inch of Original Section.
  - Maximum Torsional Moment in Foot-Pounds.
- PLATE IX.—Ductility as Shown by Transverse, Tensile, and Torsion Tests.
  - Total transverse Deflection in Inches.
  - Tensile Elongation in Parts of Original Length.
  - Torsional Elongation of Exterior Fibers in Parts of Original Length.
- PLATE X.—Resilience under Transverse and Torsional Stresses.
- PLATE XI.—Moduli of Elasticity from Transverse Tests.
- PLATE XII.—Specific Gravity—Authorities Compared.
  - Authorities: United States Board, Riche, Mallet, Calvert and Johnson.
- PLATE XIII.—Tenacity—Authorities Compared.
  - Authorities: United States Board, Mallet.
- PLATE XIV.—Heat and Electric Conductivity.
  - Heat Conductivity—Calvert and Johnson.
  - Electric Conductivity—Matthiessen.
- PLATE XV.—Hardness, Malleability, Ductility, Fusibility.
  - Order of Hardness—Mallet, Calvert and Johnson.
  - Order of Malleability—Mallet.
  - Order of Ductility—Mallet.
  - Order of Fusibility—Mallet.

RECORDS OF INDIVIDUAL TESTS.

- PLATE XVI.—Deflections by Transverse Stresses. First Series of Tests.
- PLATE XVII.—Deflections by Transverse Stresses. Second Series of Tests.
- PLATE XVIII.—Elongations by Tensile Stresses. First Series of Tests.
- PLATE XIX.—Elongations by Tensile Stresses. Second Series of Tests.
- PLATE XX.—Compressions by Compressive Stresses. First Series of Tests.
- PLATE XXI.—Compressions by Compressive Stresses. Second Series of Tests.

PLATE 1.

Tests by Transverse Stress.

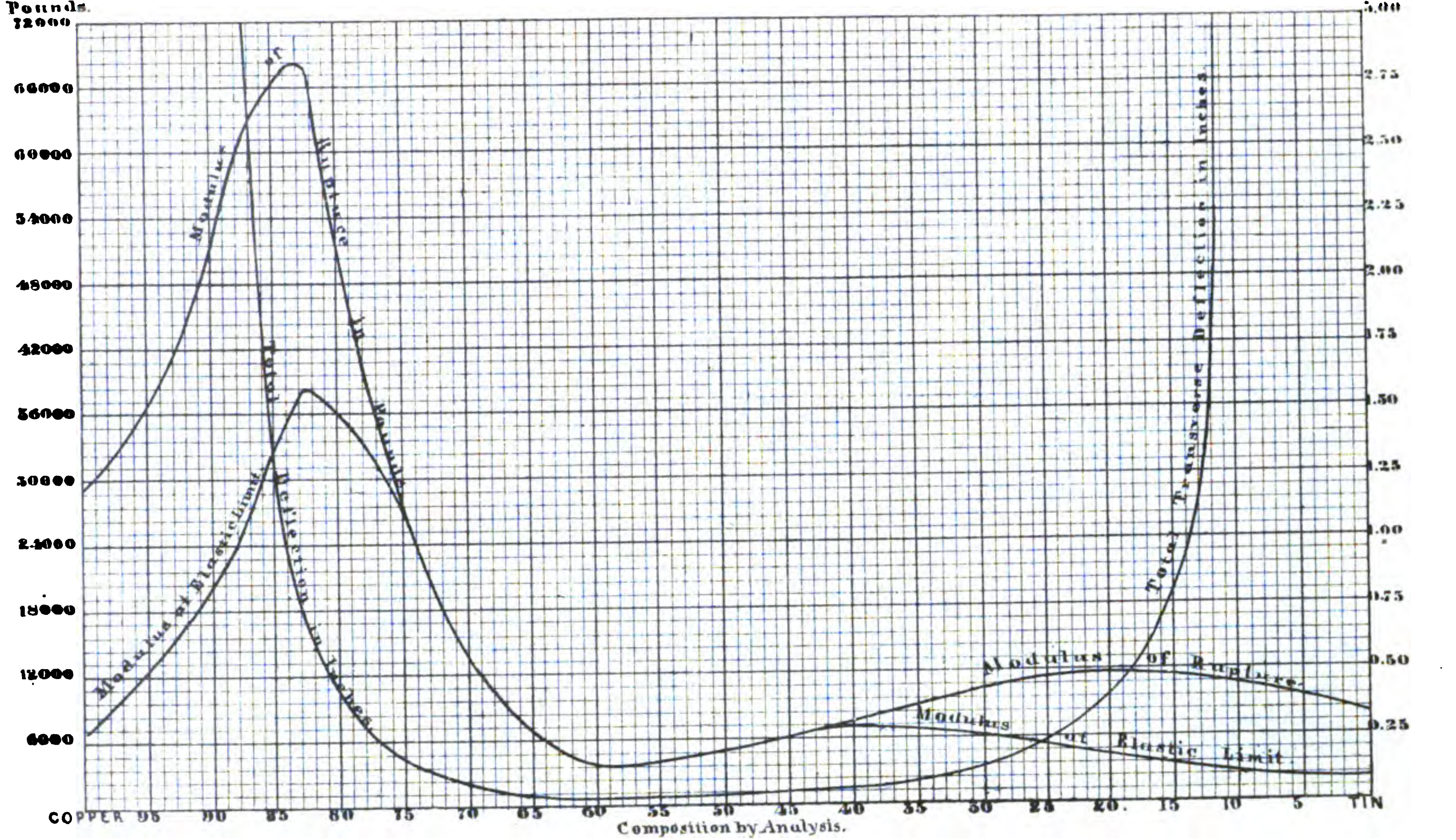


PLATE II.

Tests by Tensile Stress.

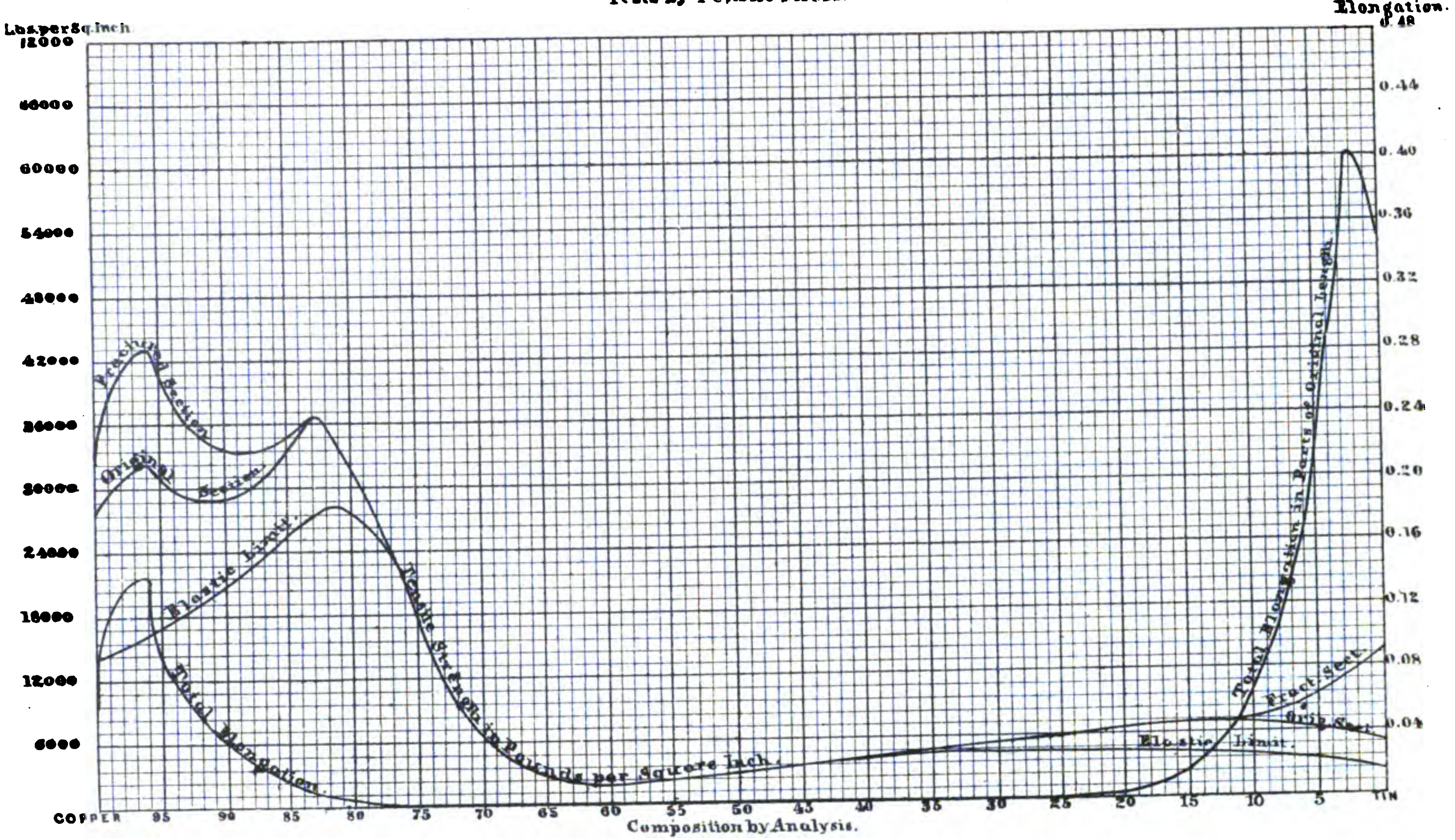


PLATE III.

Tests by Torsional Stress

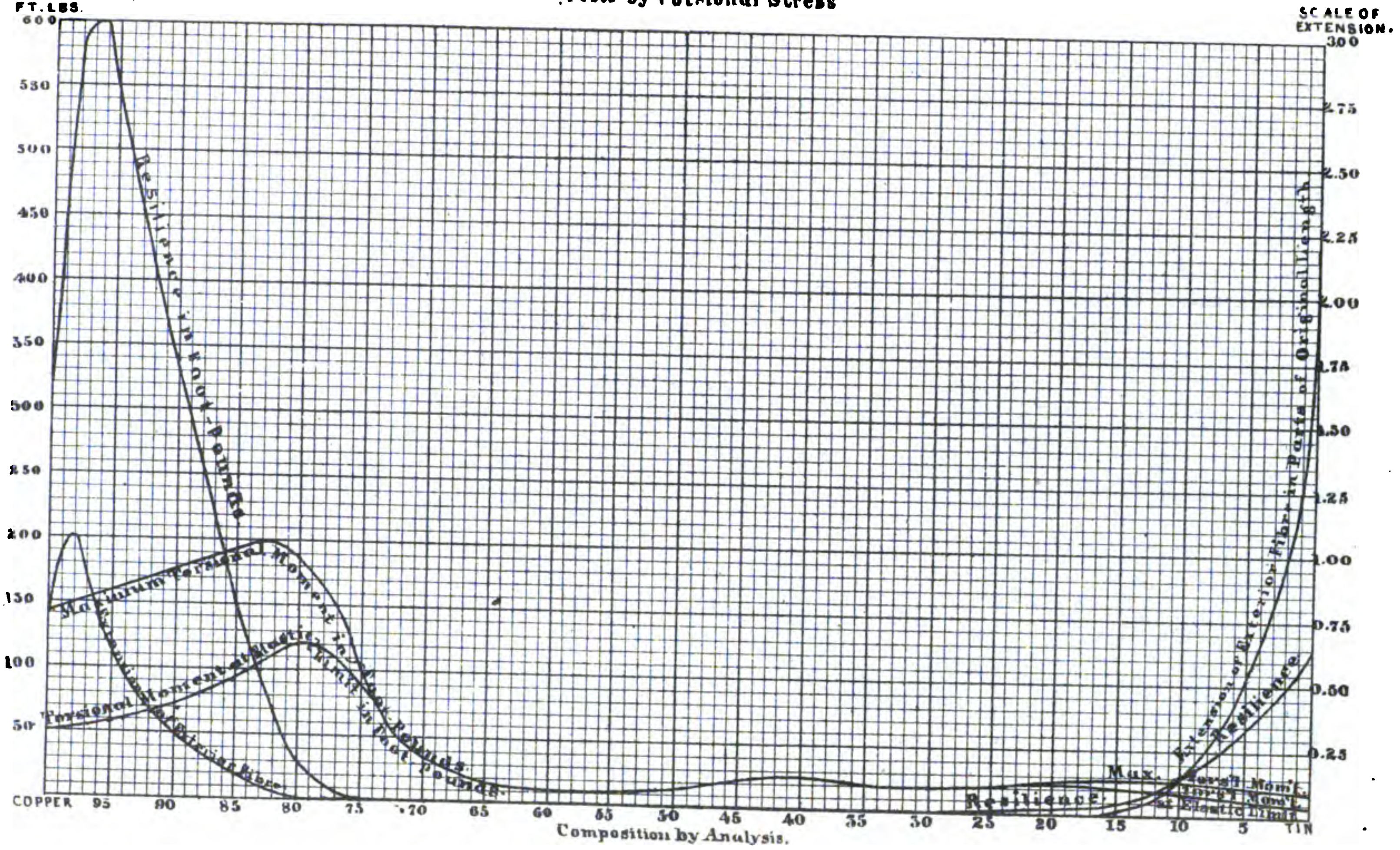


PLATE IV.

Tests by Compressive Stress.

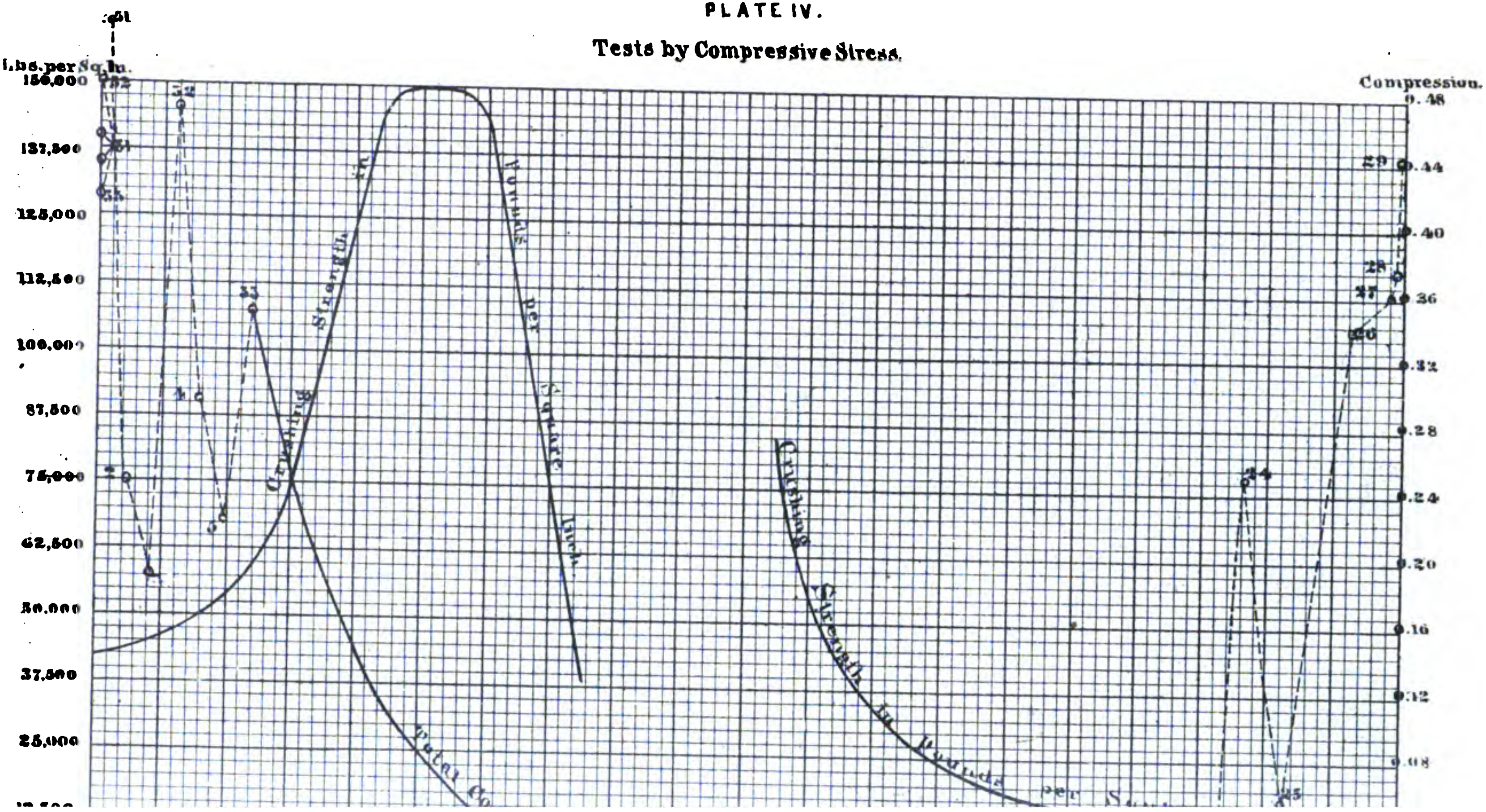


PLATE V.

Mean Specific Gravity.

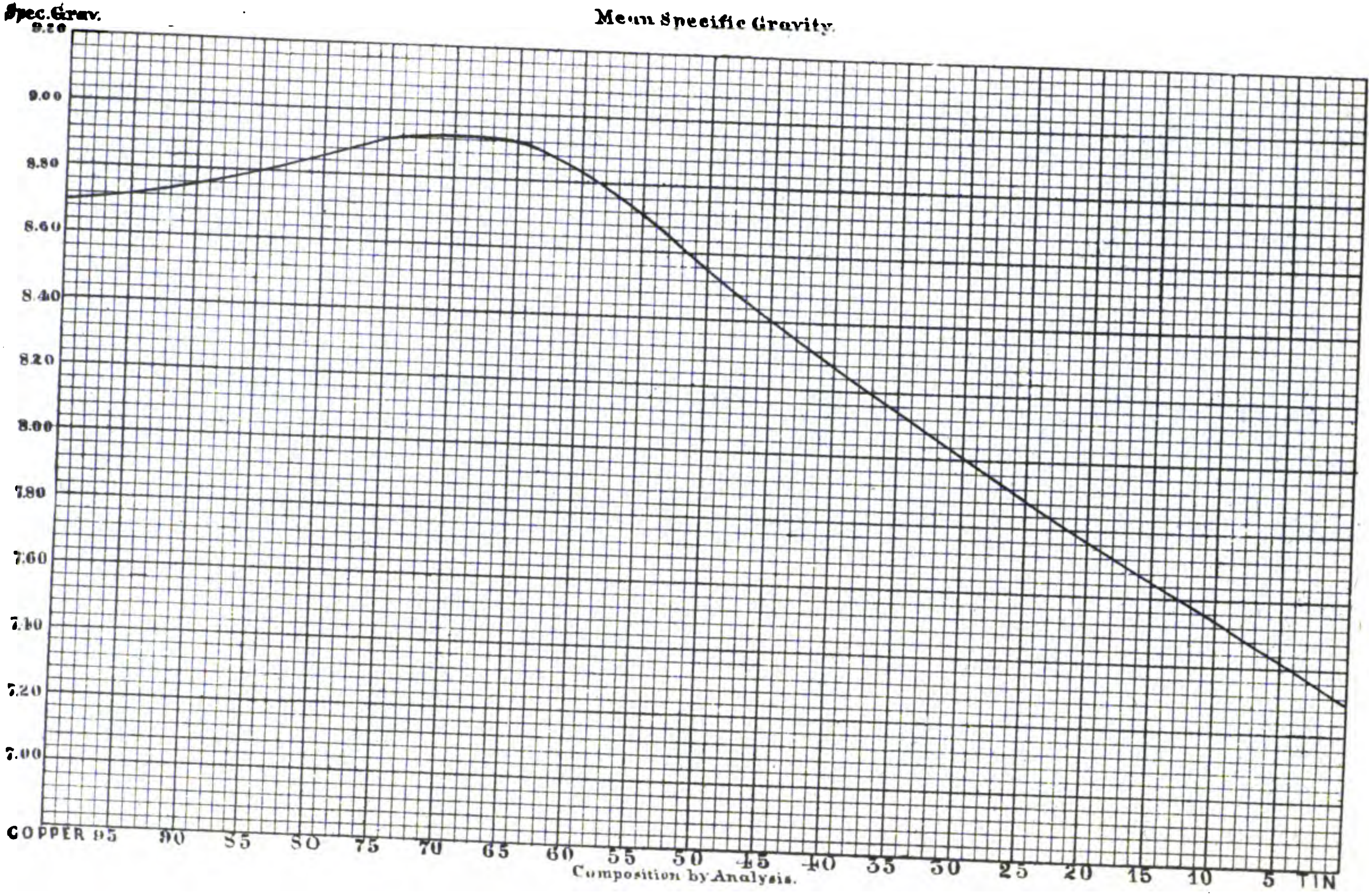


PLATE VI.

Variation of Analyses from Original Compositions.

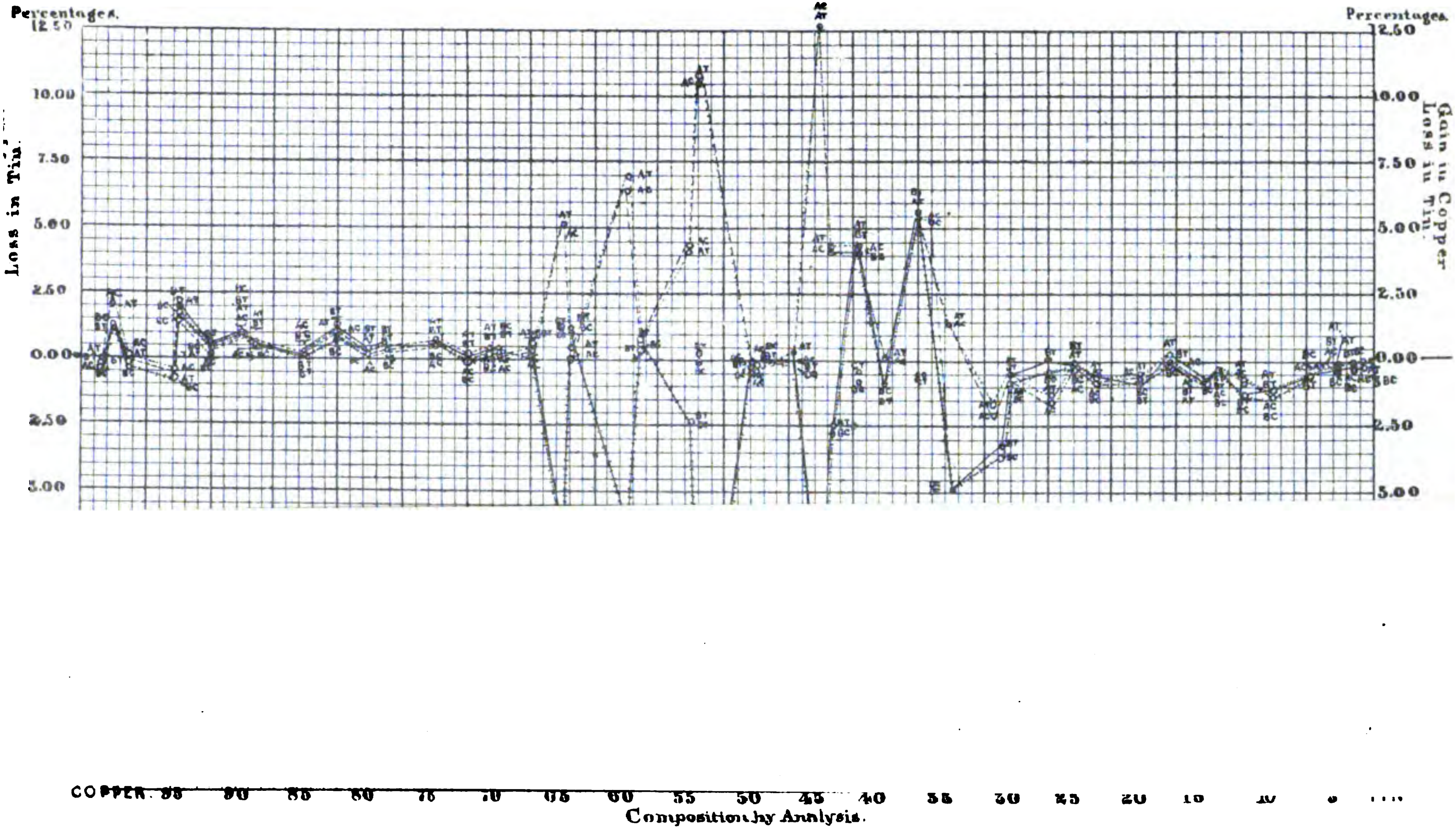


PLATE VII.

Comparison of Transverse, Tensile, Torsional and Compressive Resistances.

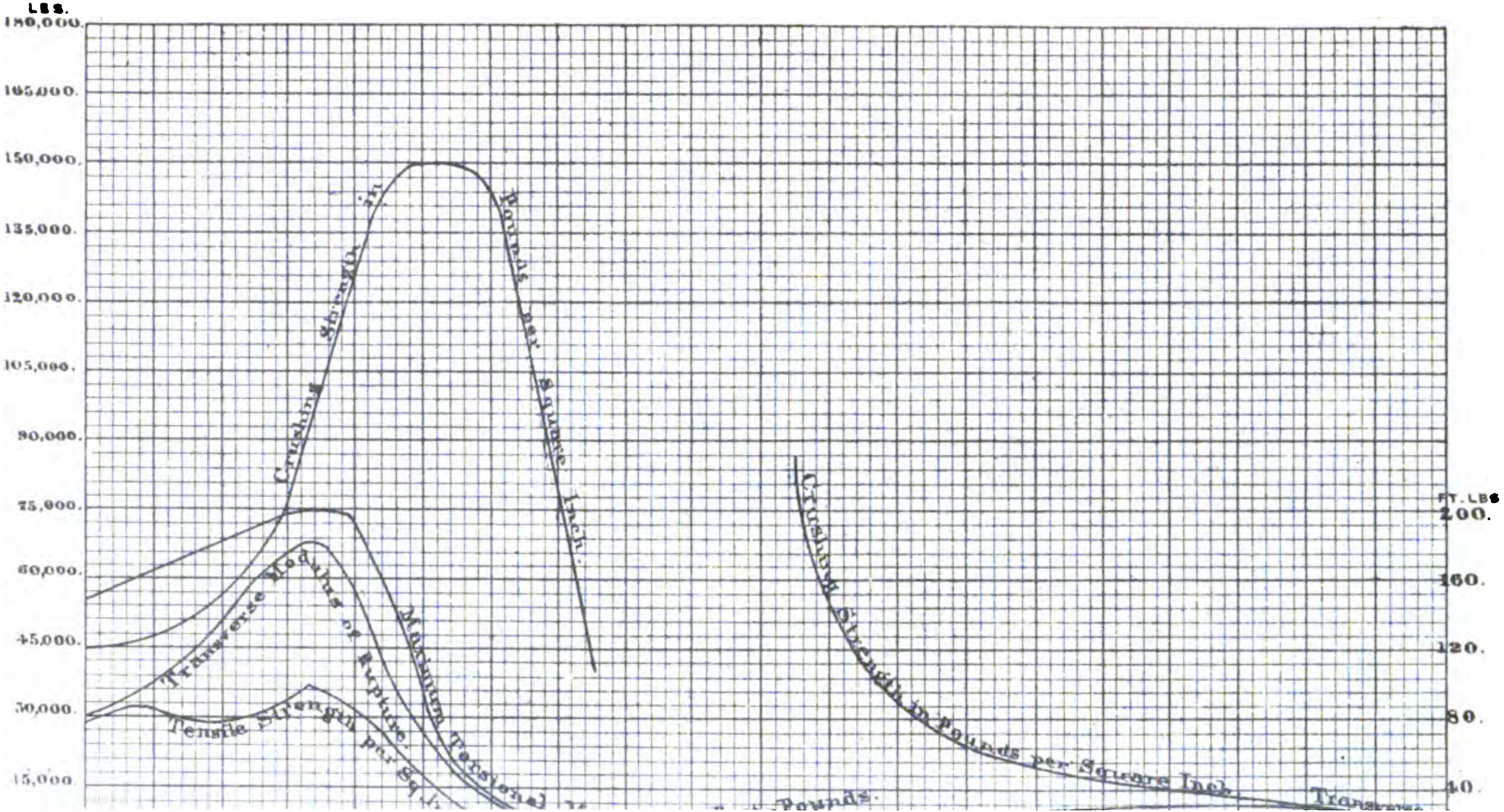


PLATE VIII.

Comparison of Transverse, Tensile and Torsional Resistances.

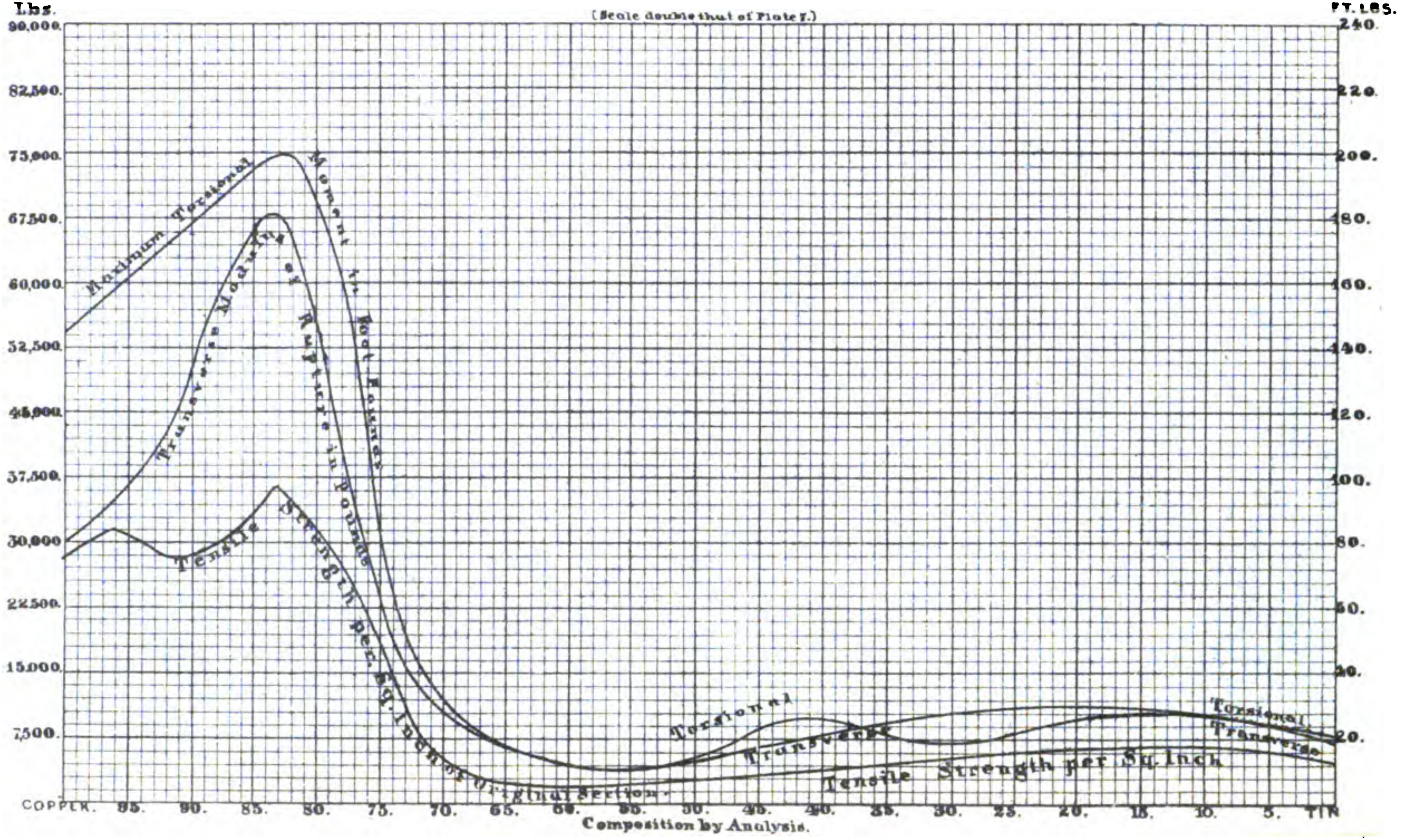
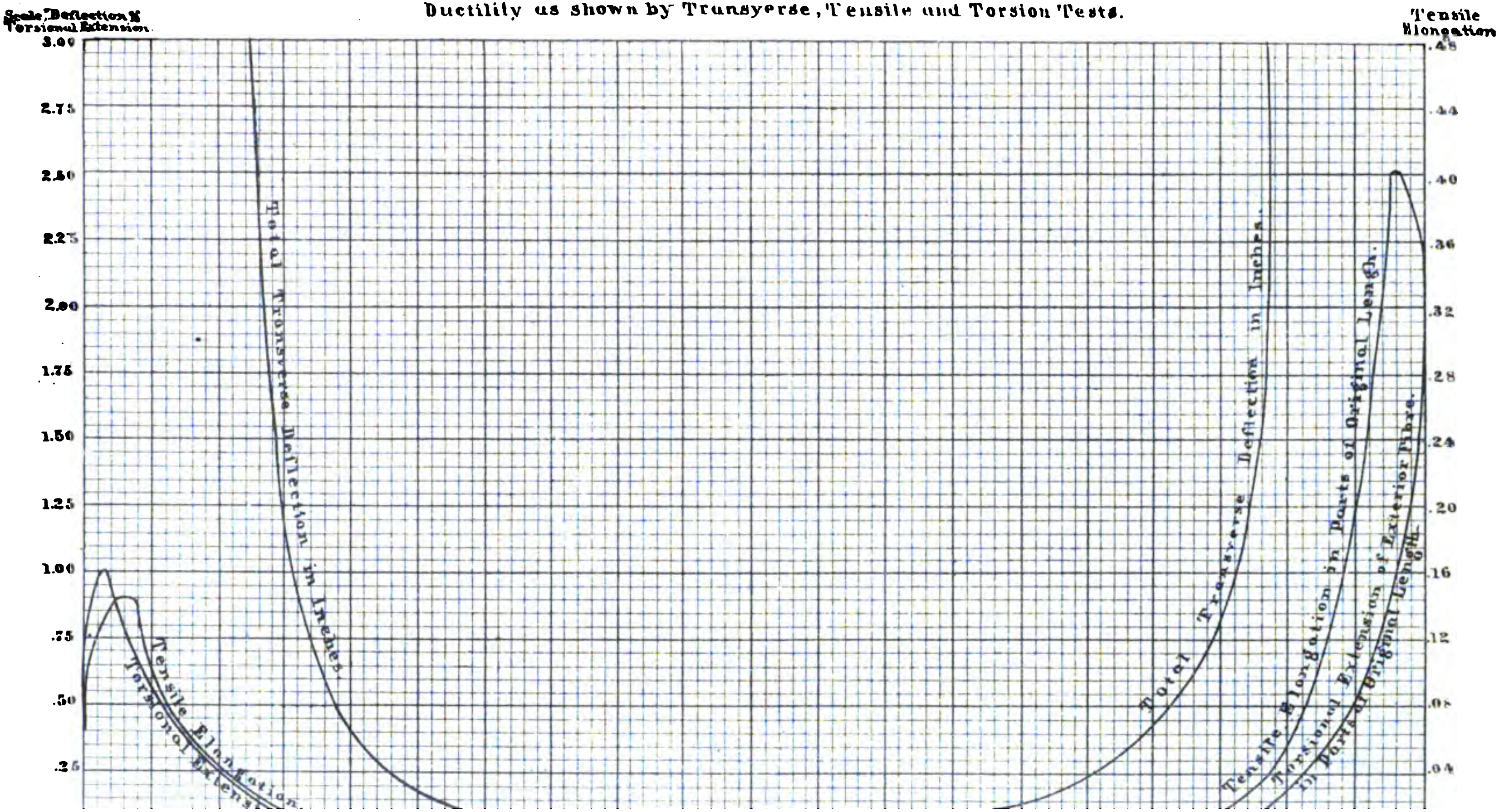
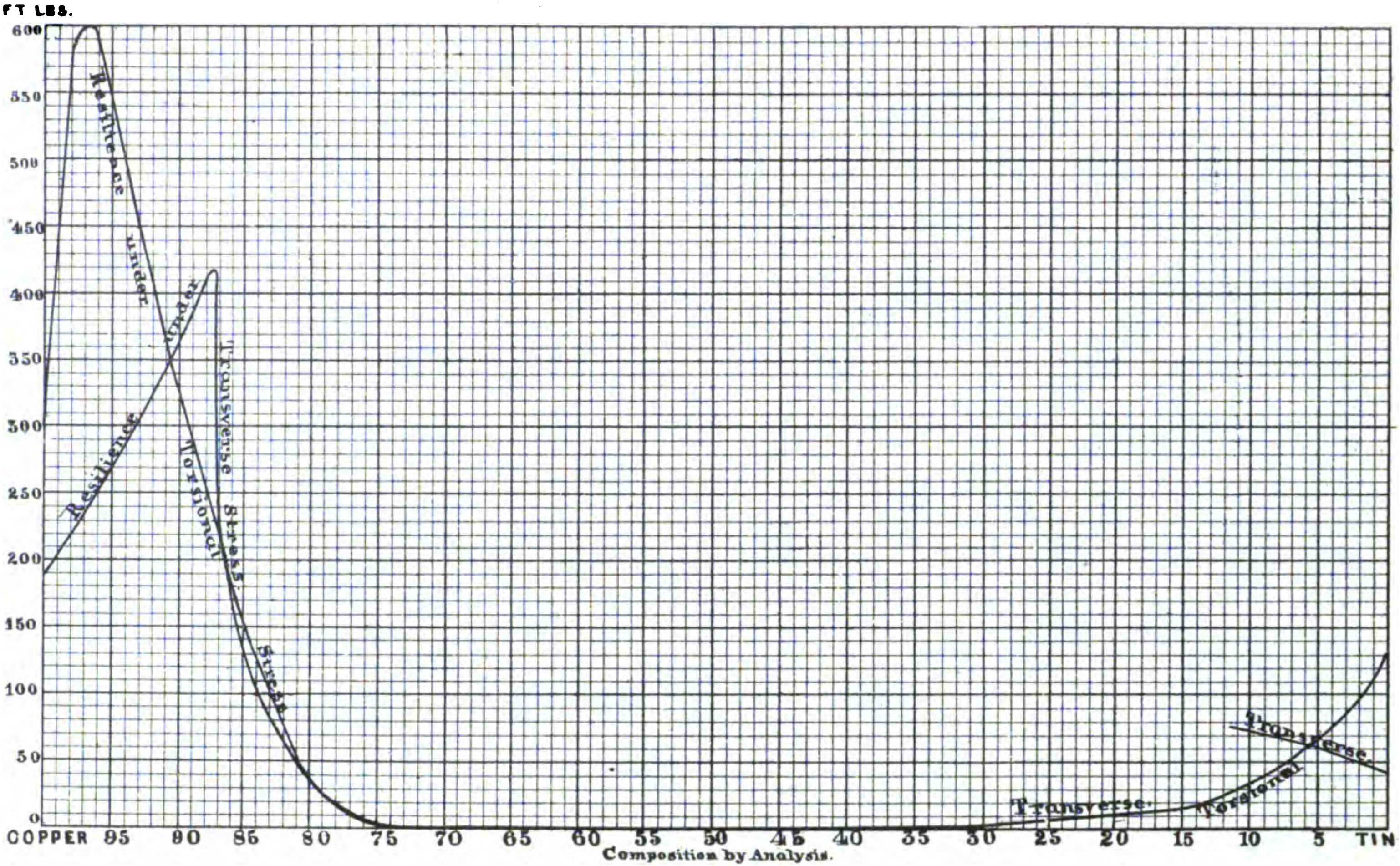


PLATE IX.

Ductility as shown by Transverse, Tensile and Torsion Tests.

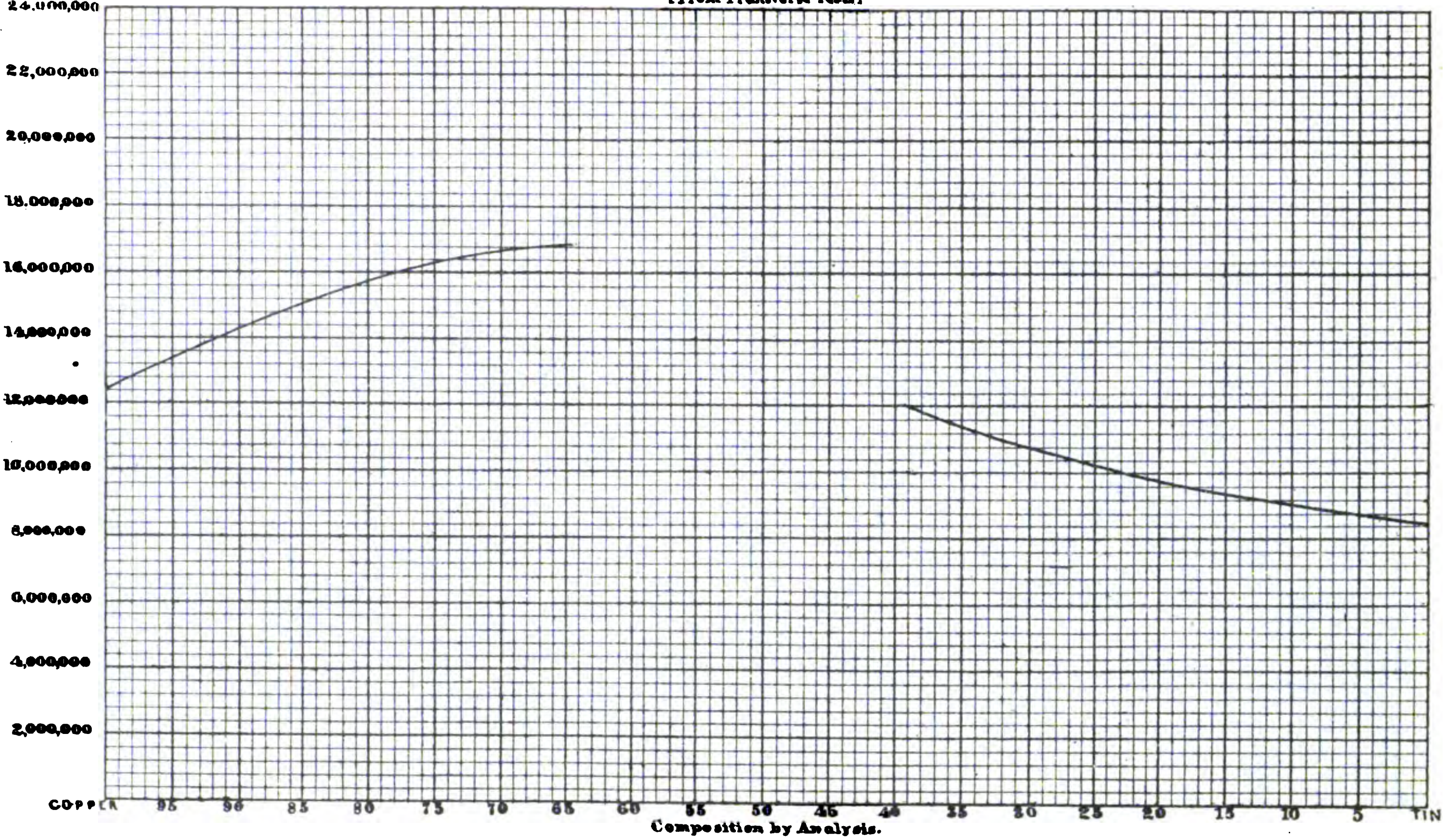


Resilience under Transverse and Torsional Stresses.



Moduli of Elasticity.

[From Transverse Tests]



Specific Gravity. Authorities compared.

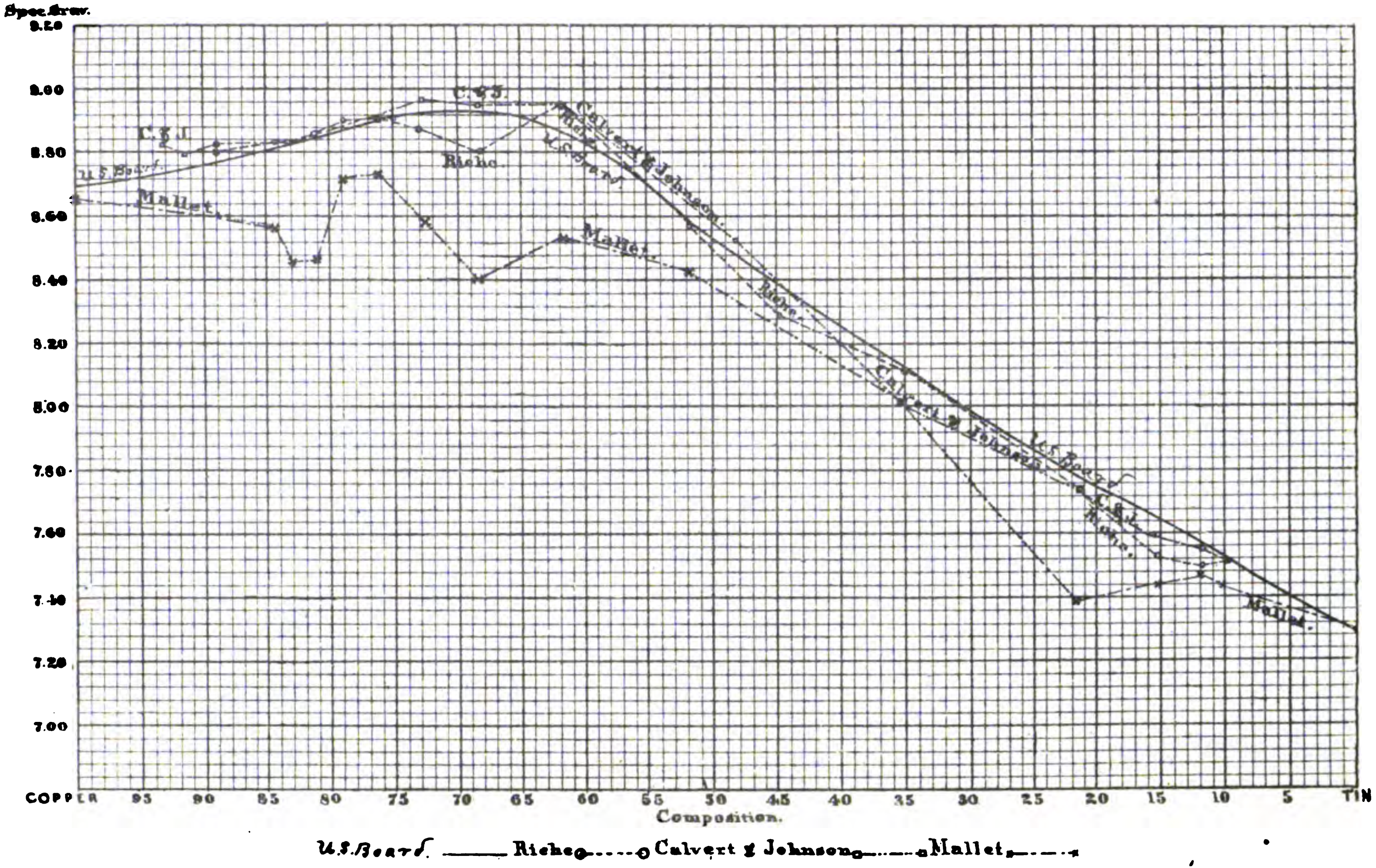


PLATE XIII.

Tenucity. Authorities compared.

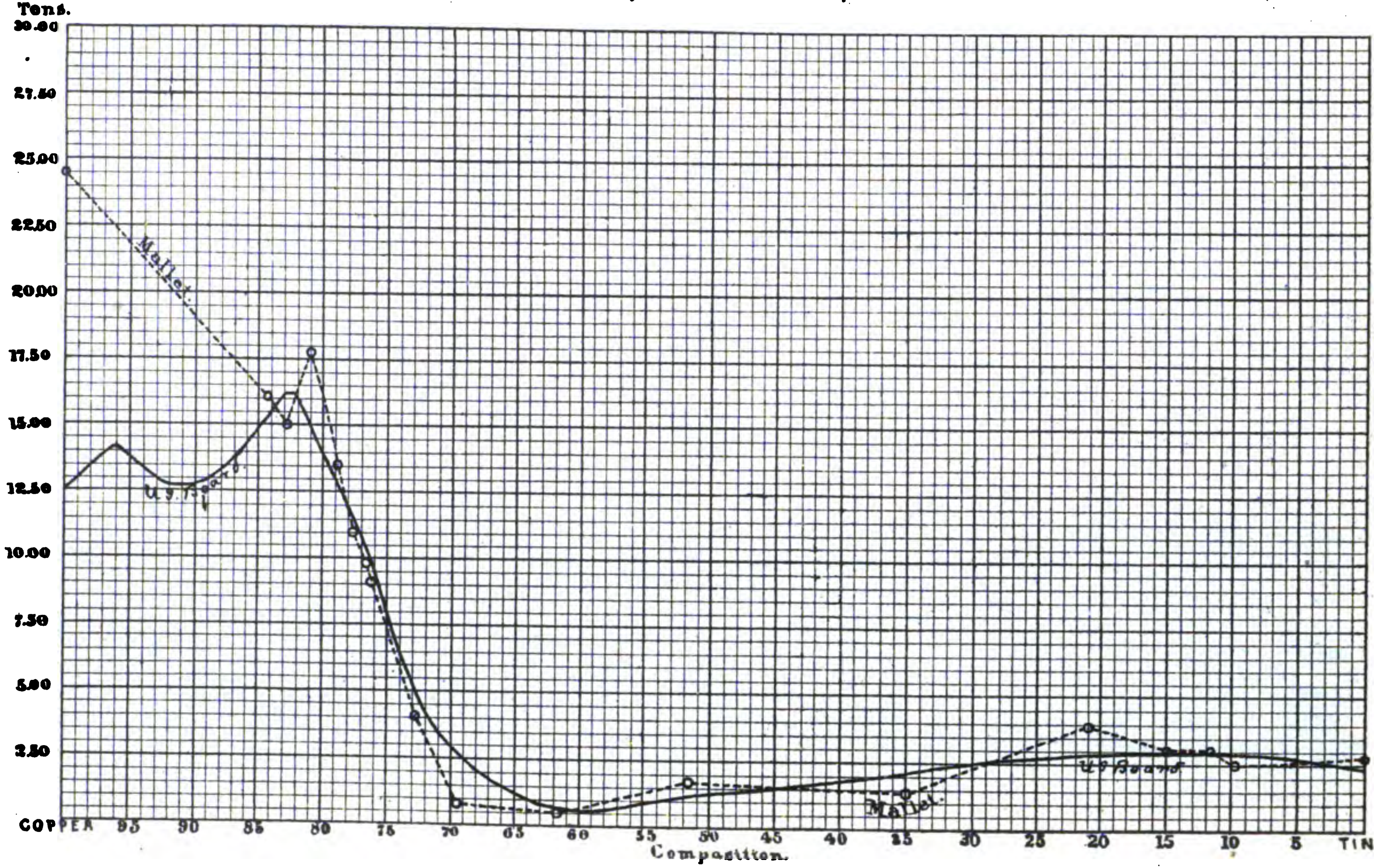
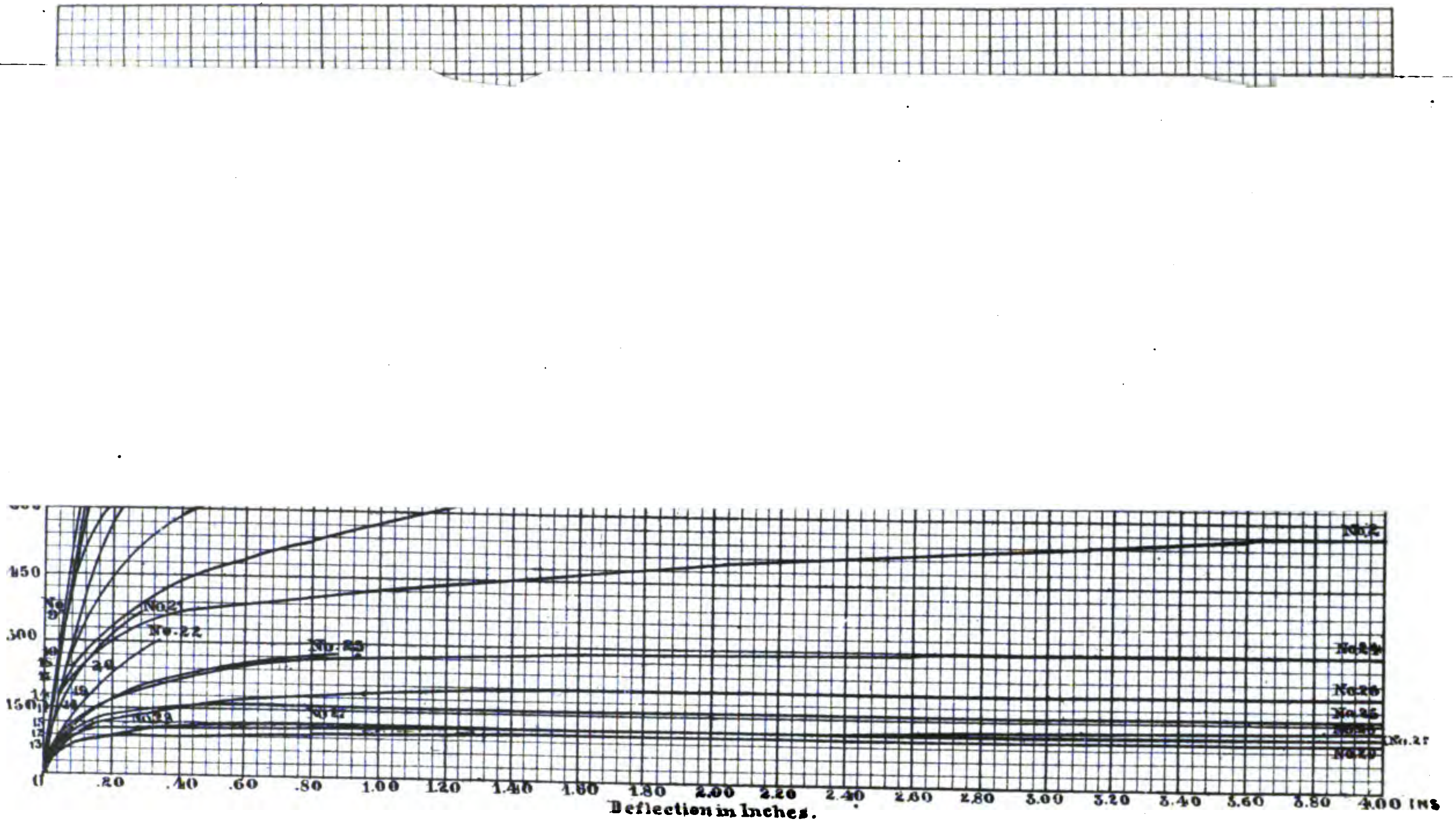


PLATE XIV.

Heat and Electric Conductivity



Tests by Transverse Stress.

[1st. Series]

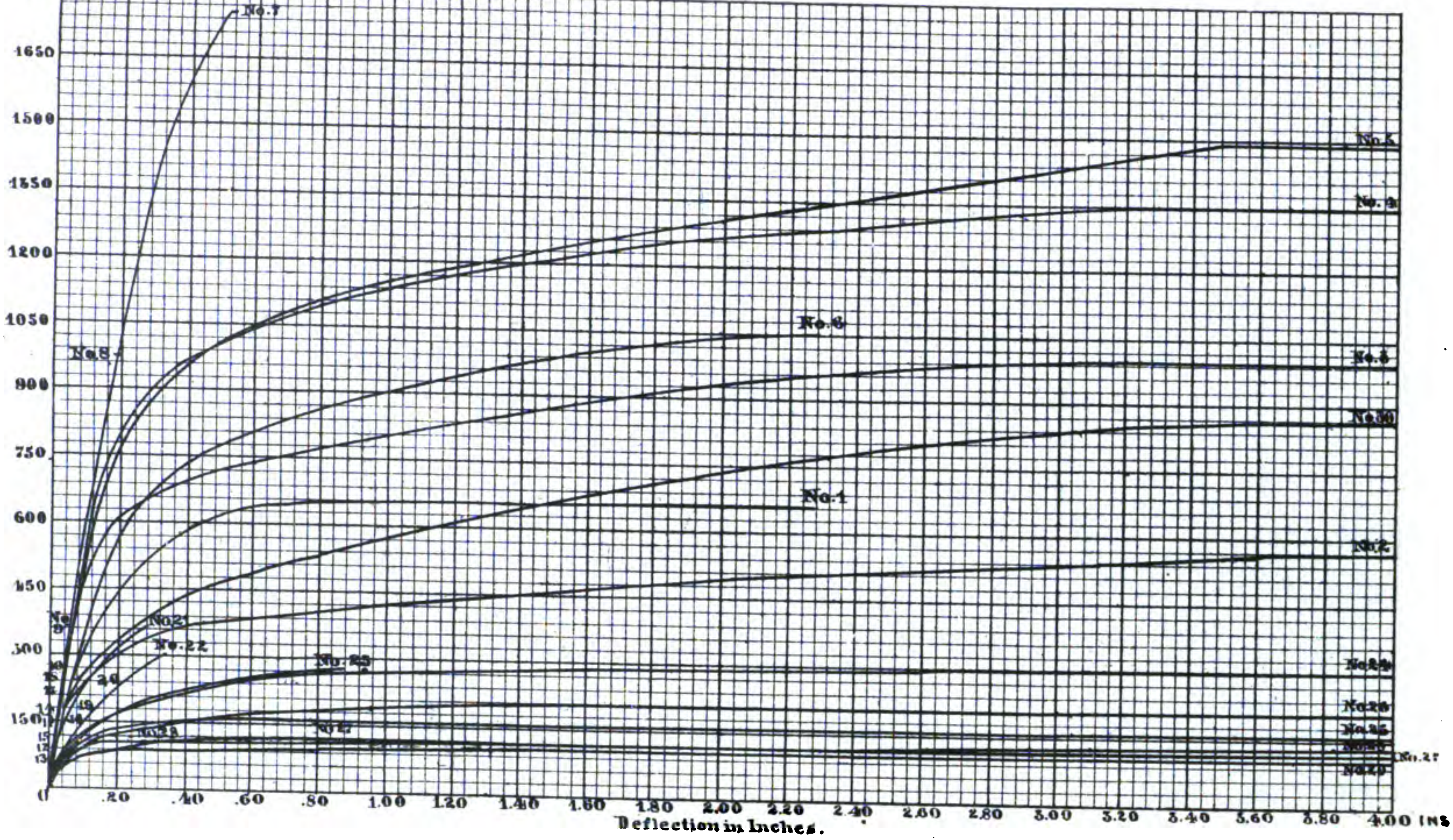
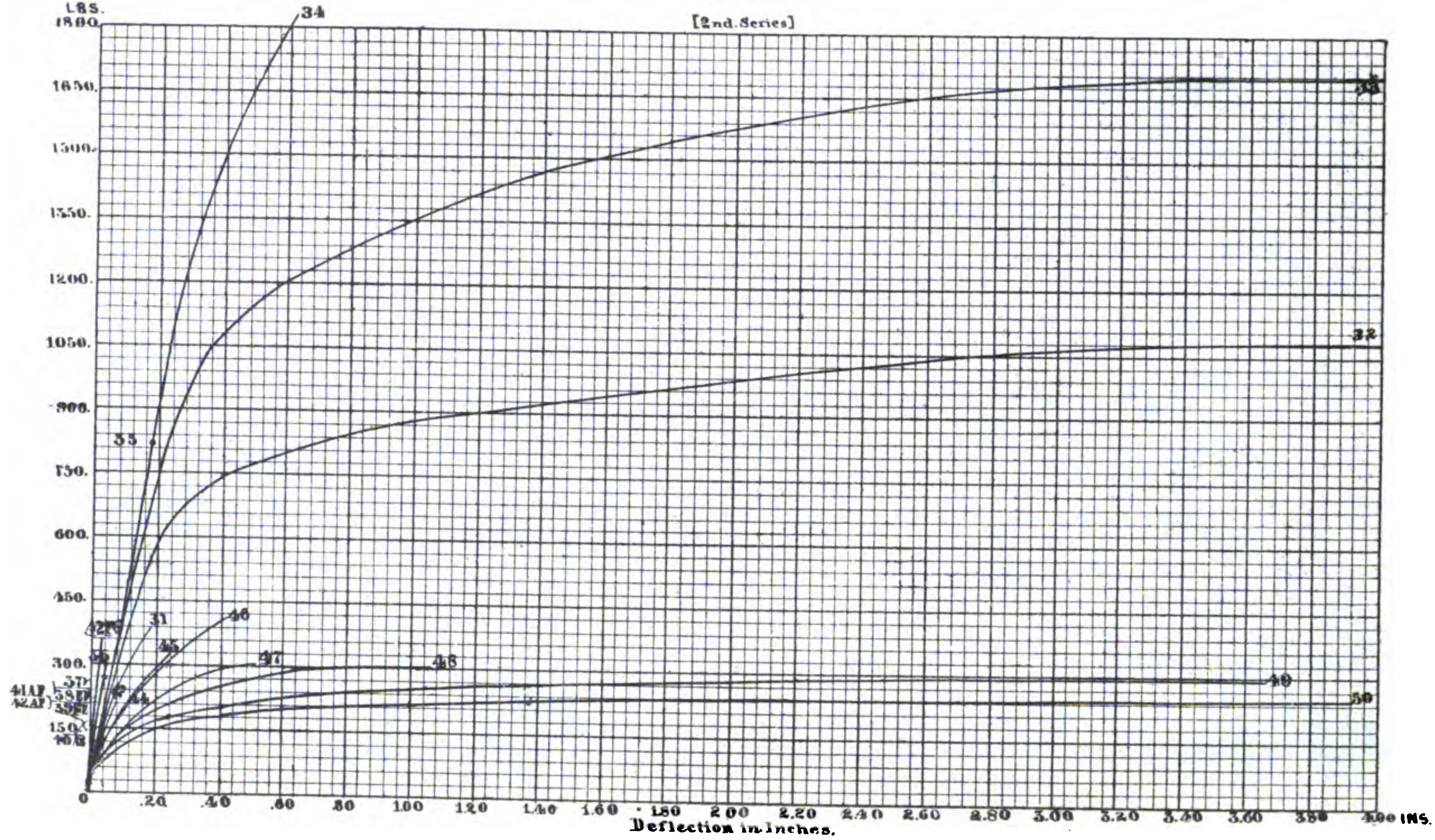


PLATE XVII.

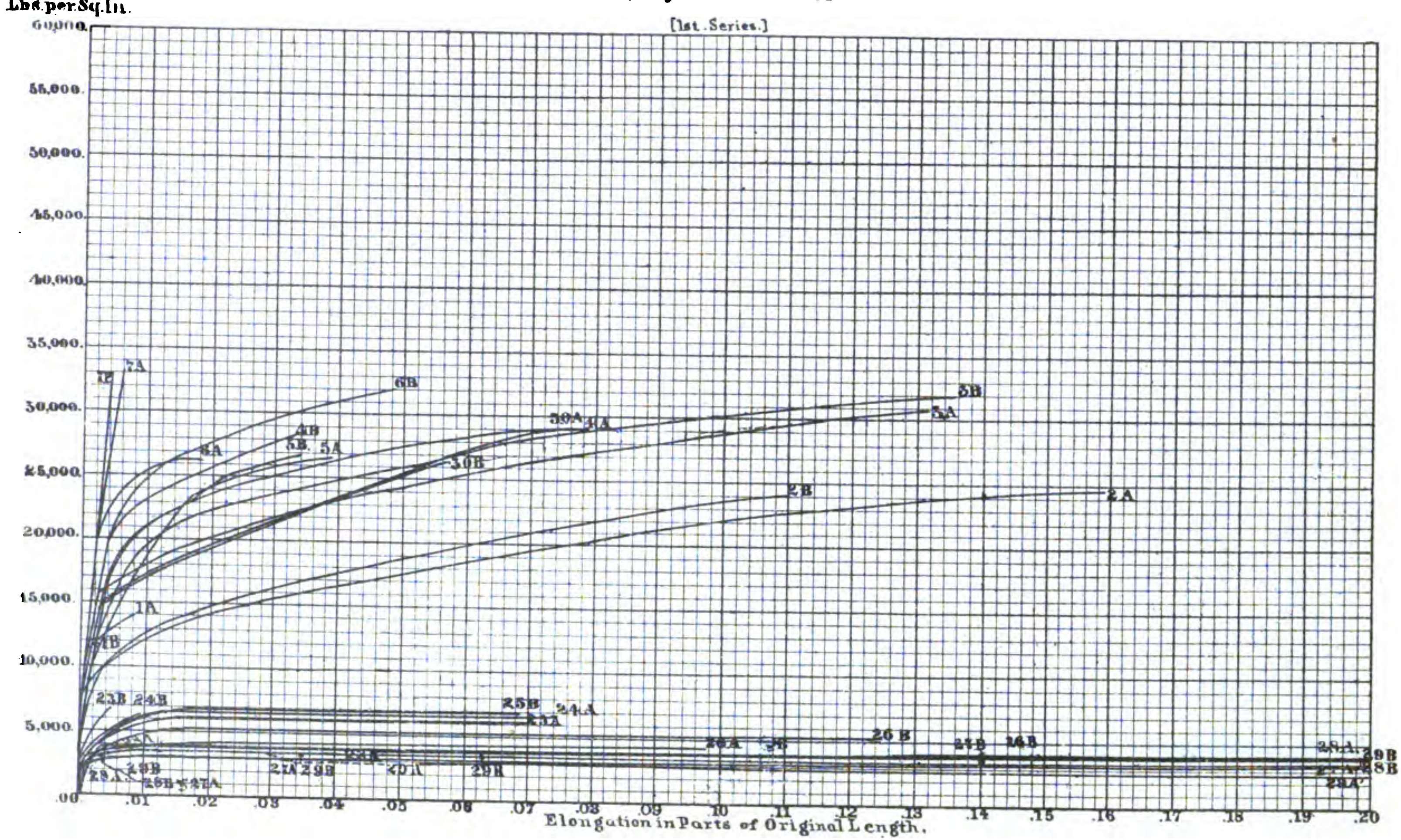
Tests by Transverse Stress.

[2nd. Series]



Tests by Tensile Stress.

[1st. Series.]



Tests by Tensile Stress.

[2nd Series.]

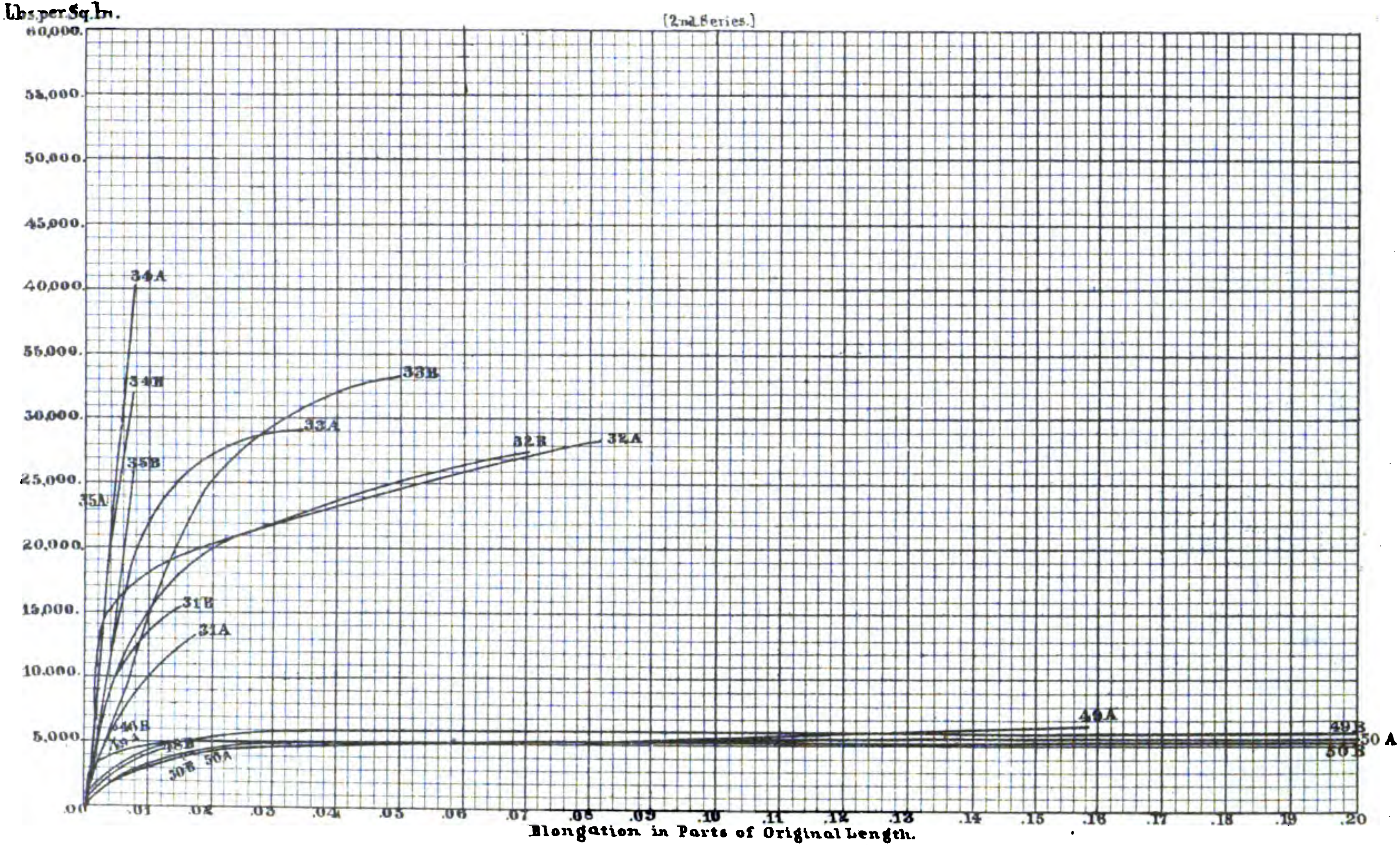
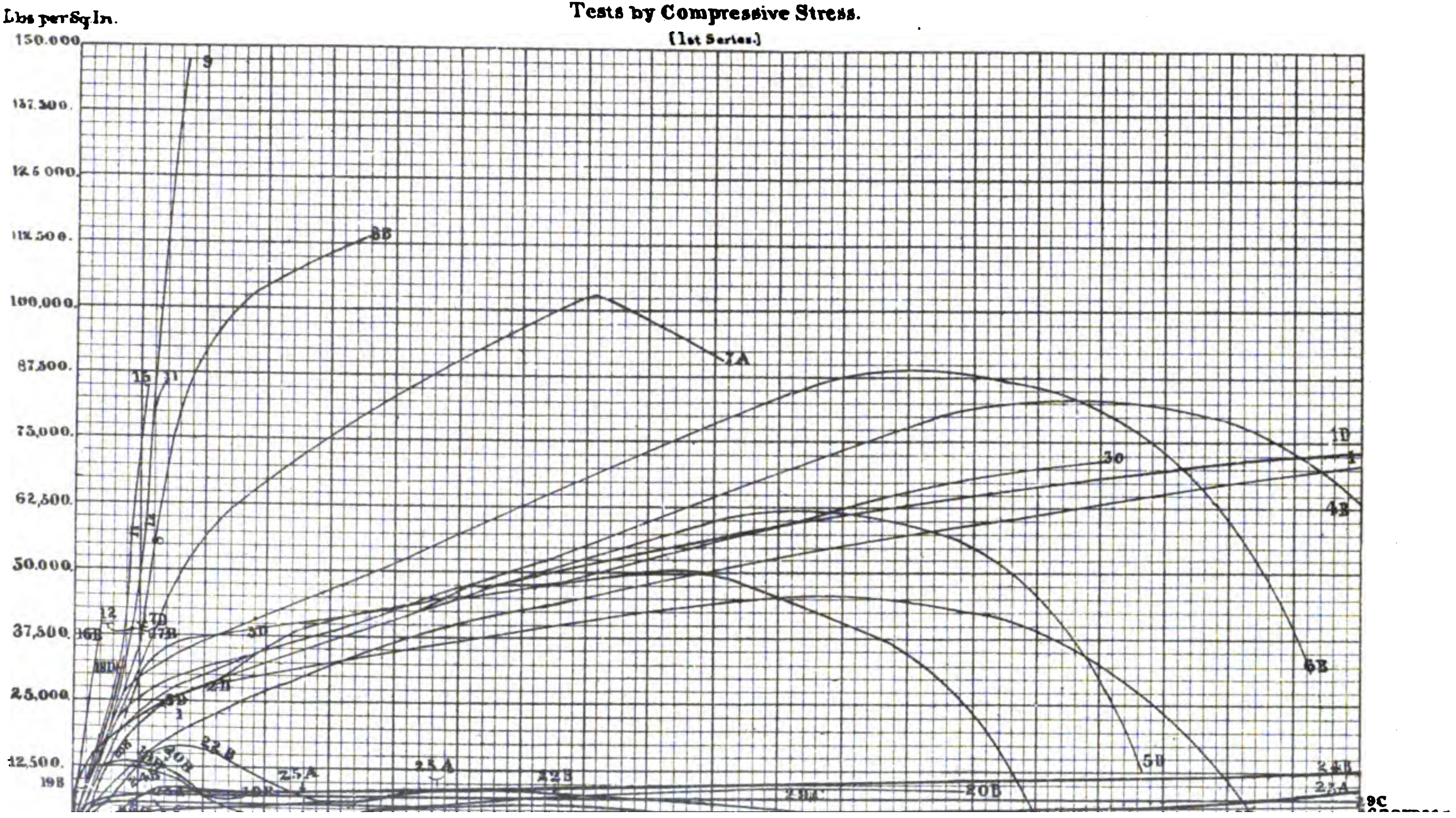


PLATE XX

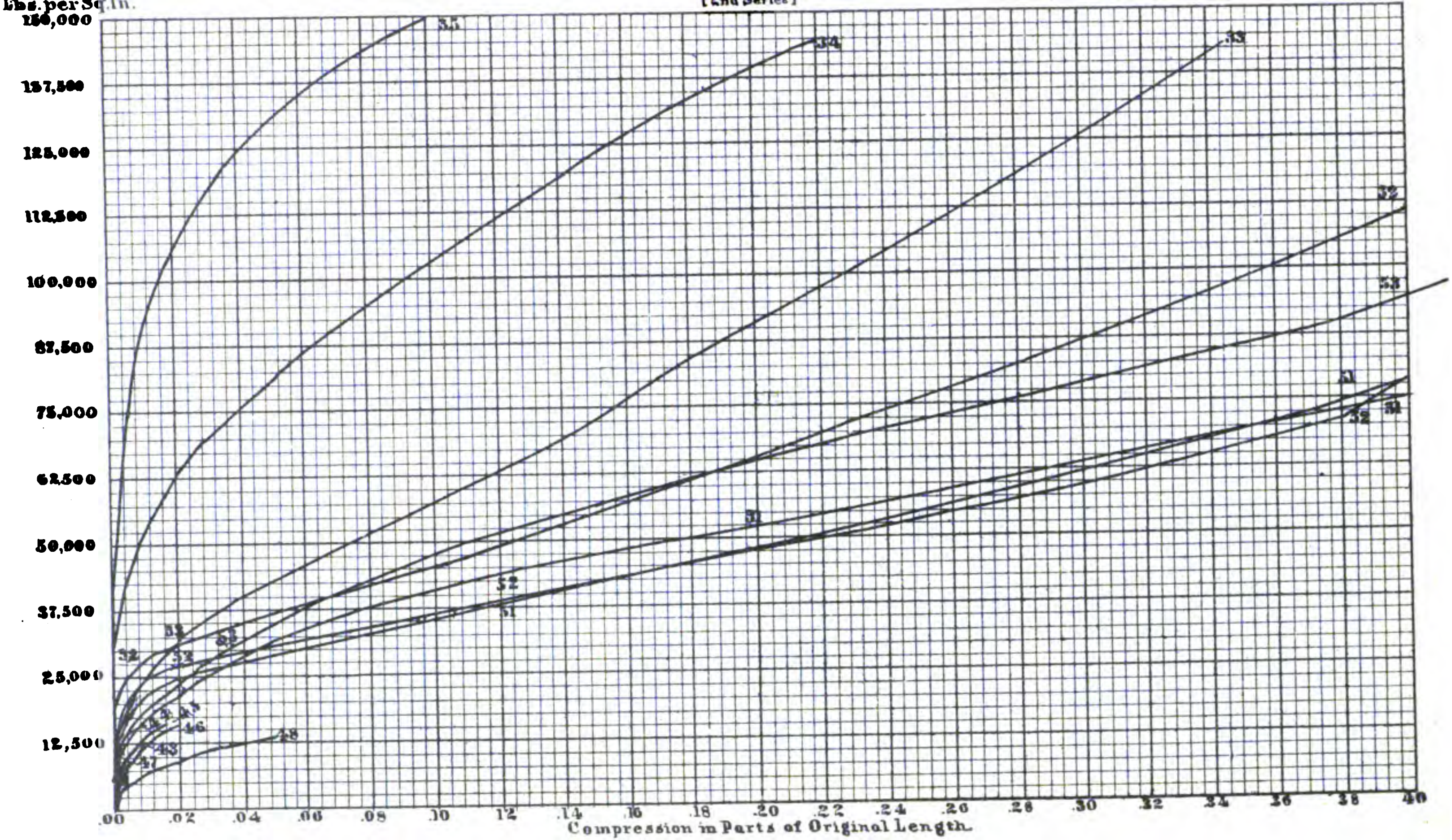
Tests by Compressive Stress.

(1st Series.)



Tests by Compressive Stress.

[2nd Series]



PLATES XXII–LXXVI.

FAC-SIMILE

AUTOGRAPHIC STRAIN DIAGRAMS

OF

TESTS BY TORSION

IN THE

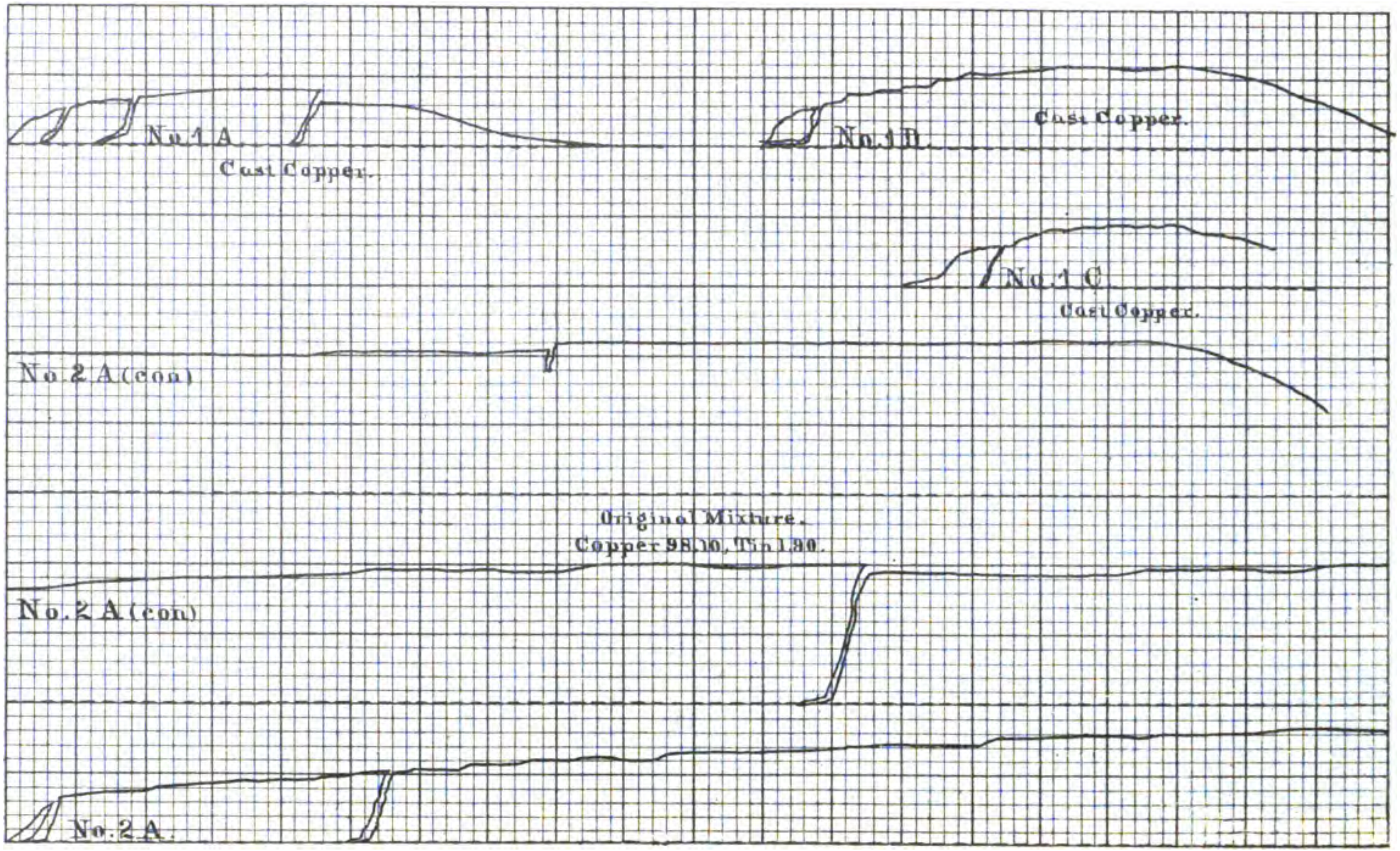
AUTOGRAPHIC RECORDING TESTING MACHINE

OF

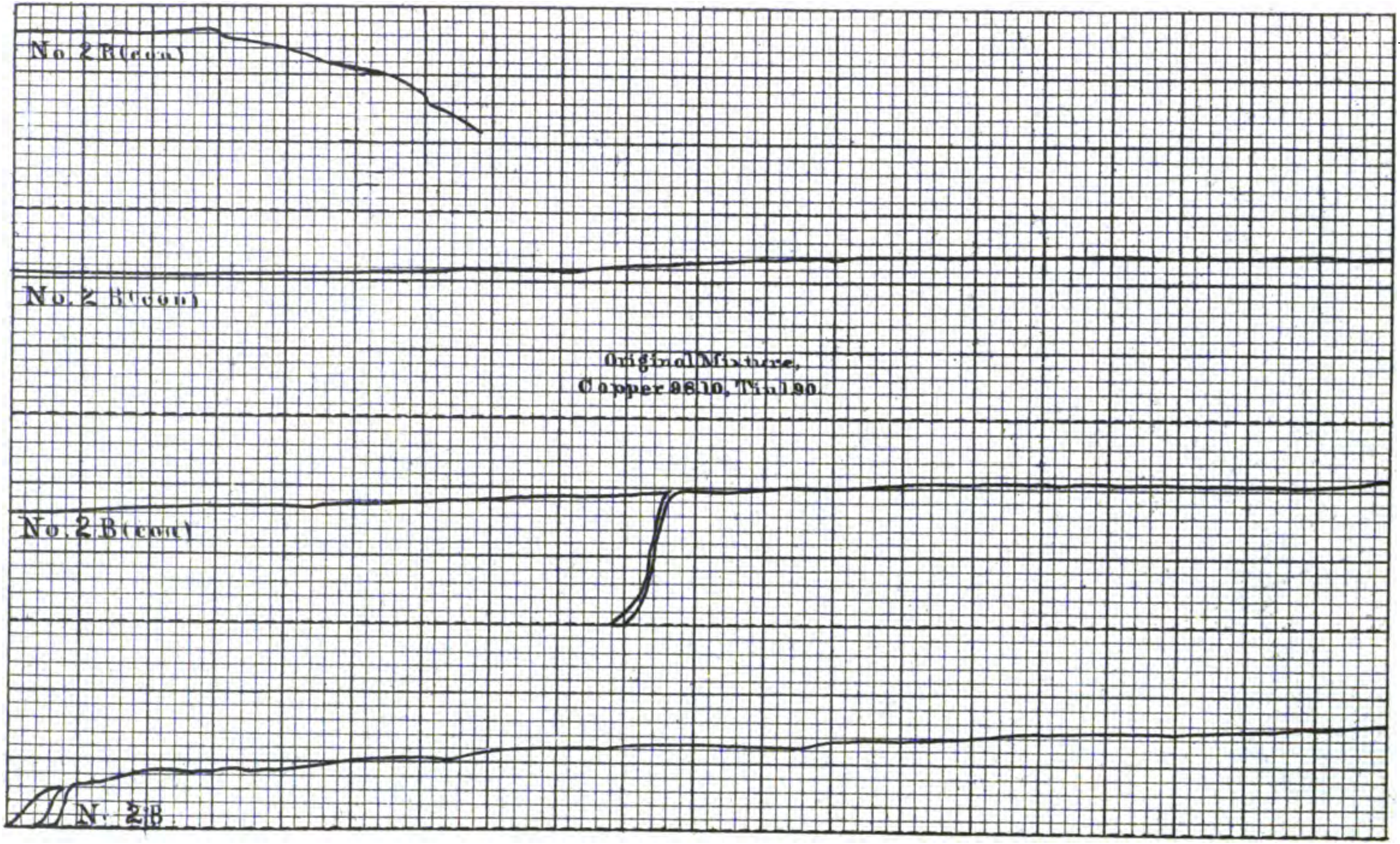
PROF. R. H. THURSTON.

PLATE XXII.

Fac-Simile Autographic Strain Diagrams.



Fac-Simile Autographic Strain Diagrams.



Fac-Simile Autographic Strain Diagrams.

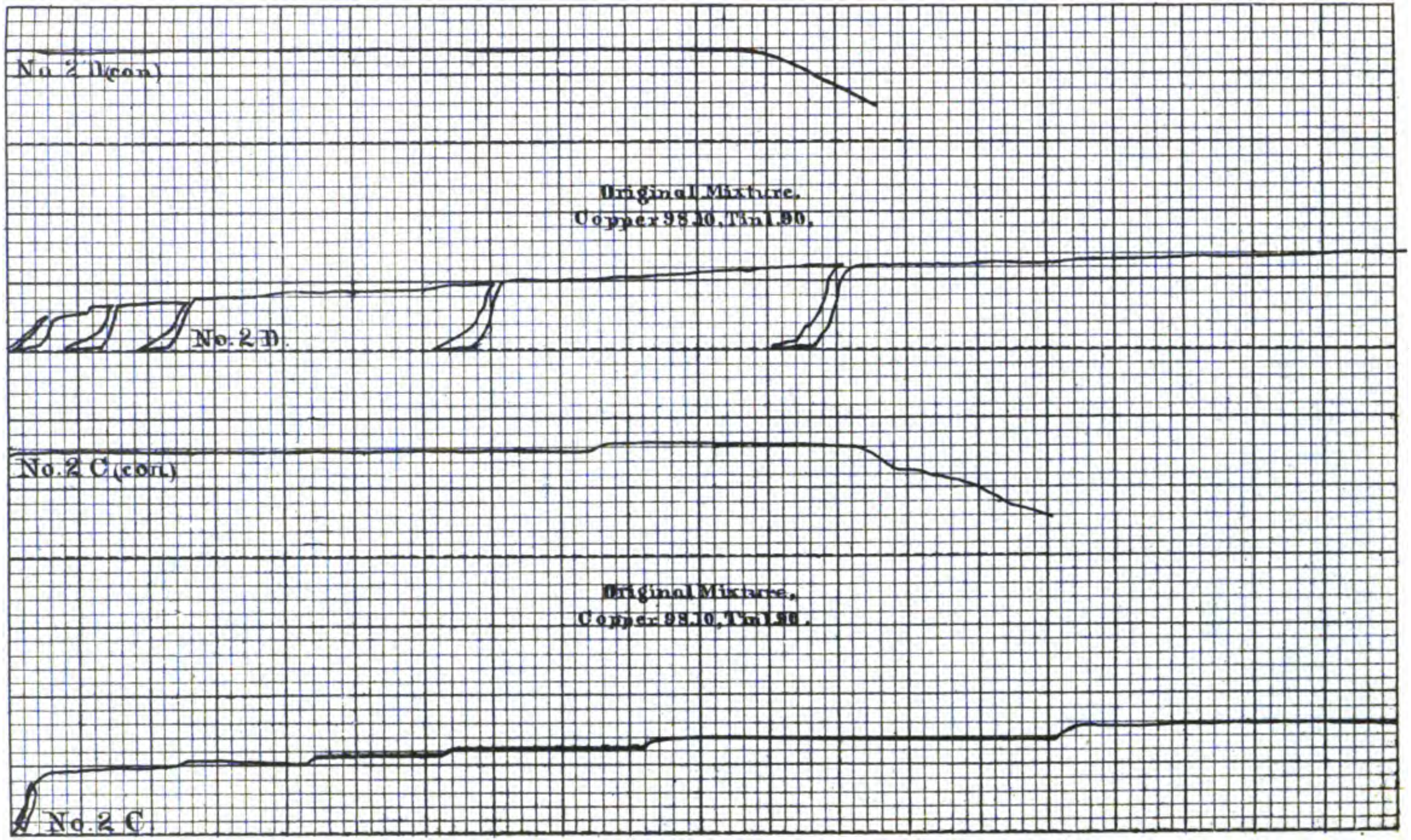


PLATE XXV.

Fac-Simile Autographic Strain Diagrams.

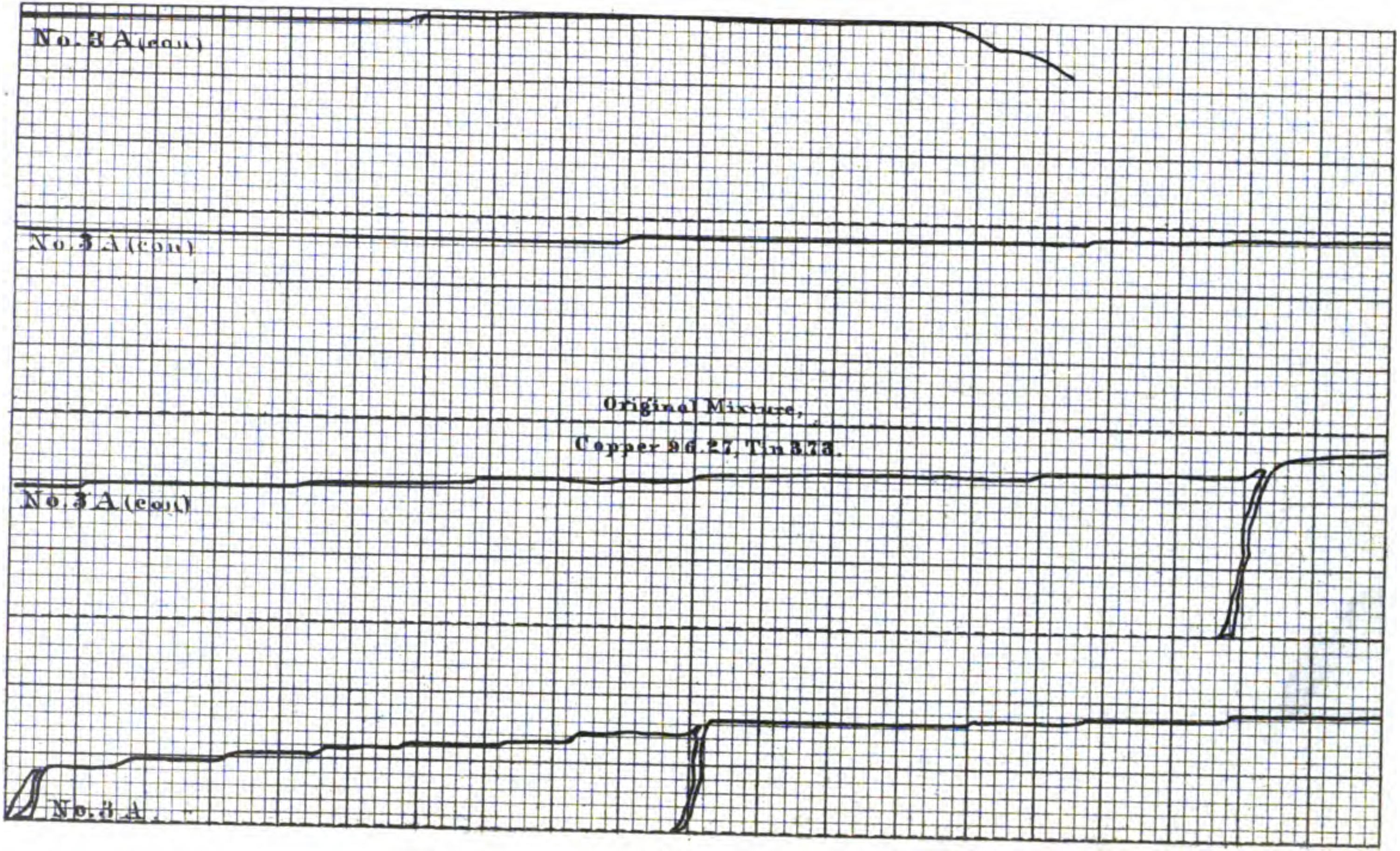
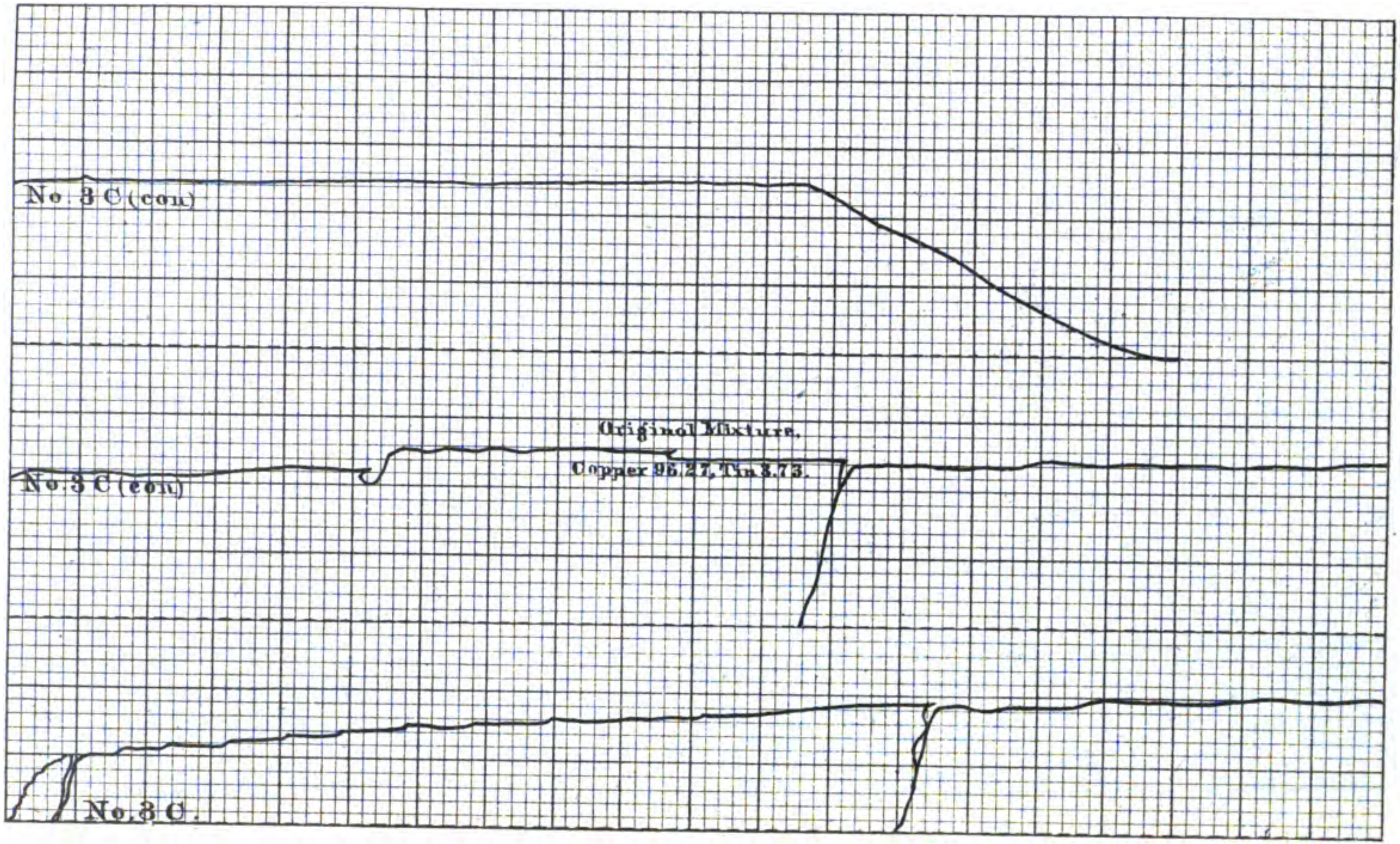
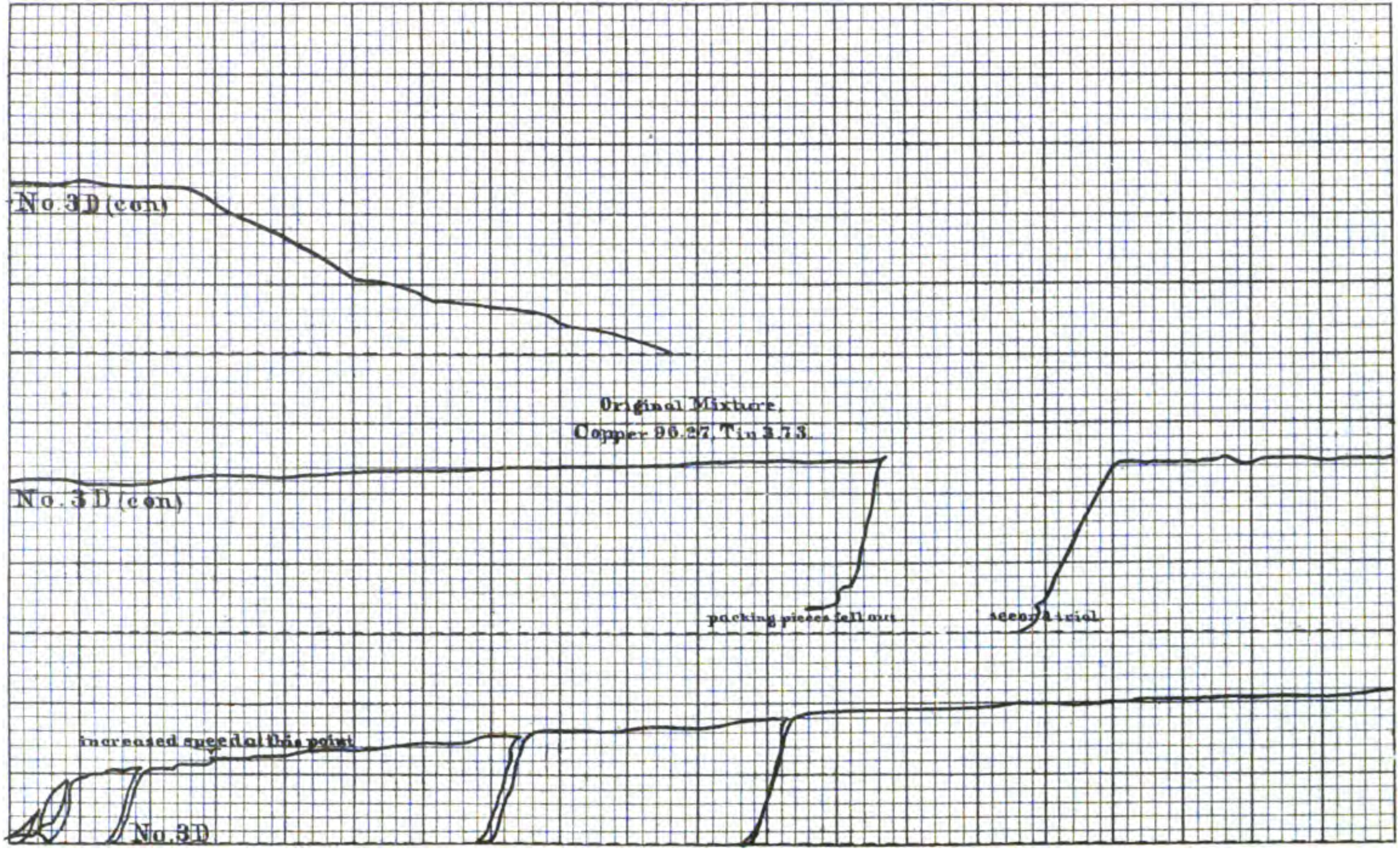


PLATE XXVI.

Fac-Simile Autographic Strain Diagrams.



Fac-Simile Autographic Strain Diagrams.



Fac-Simile Autographic Strain Diagrams.

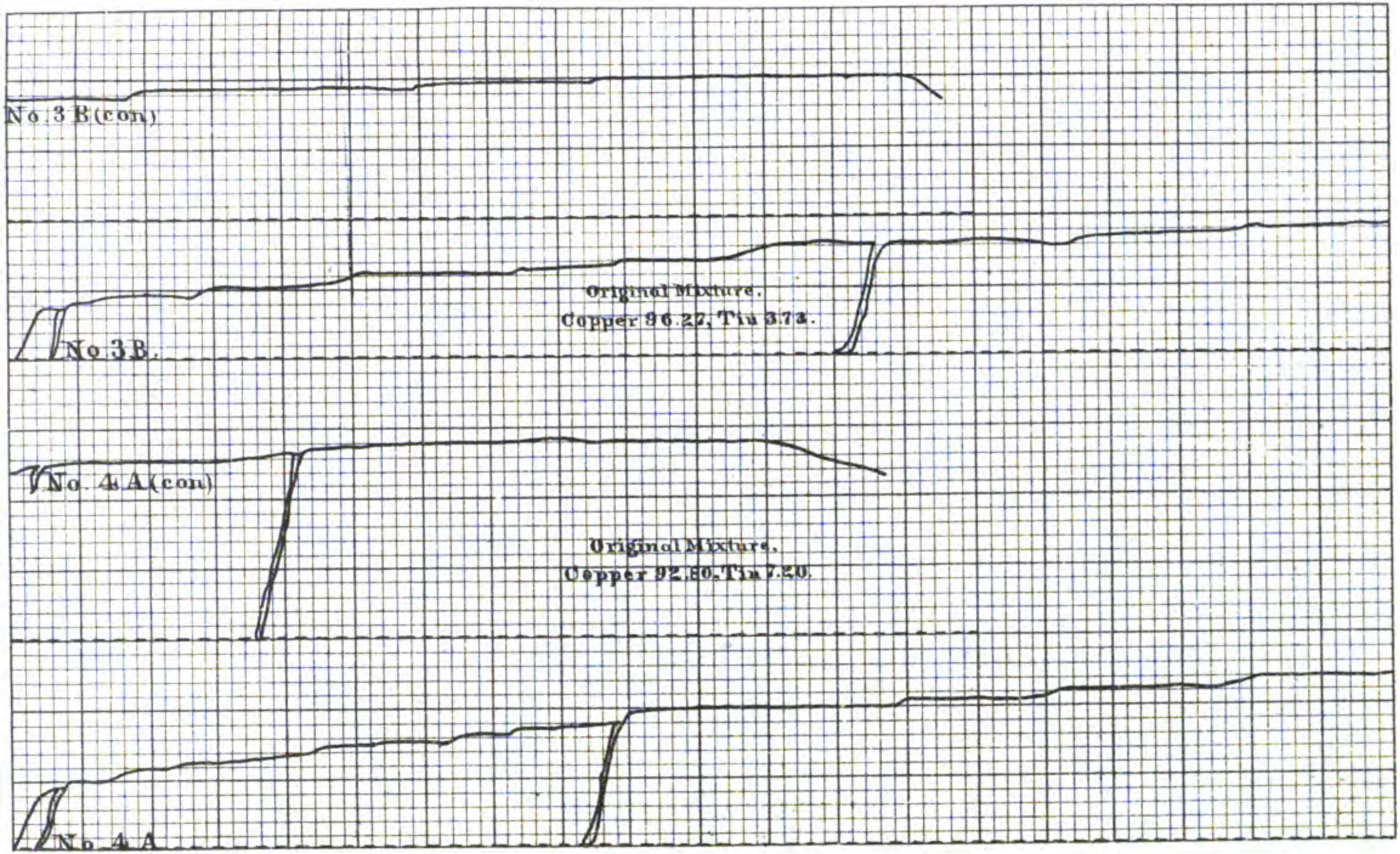


PLATE XXIX.

·Fac-Simile Autographic Strain Diagrams.

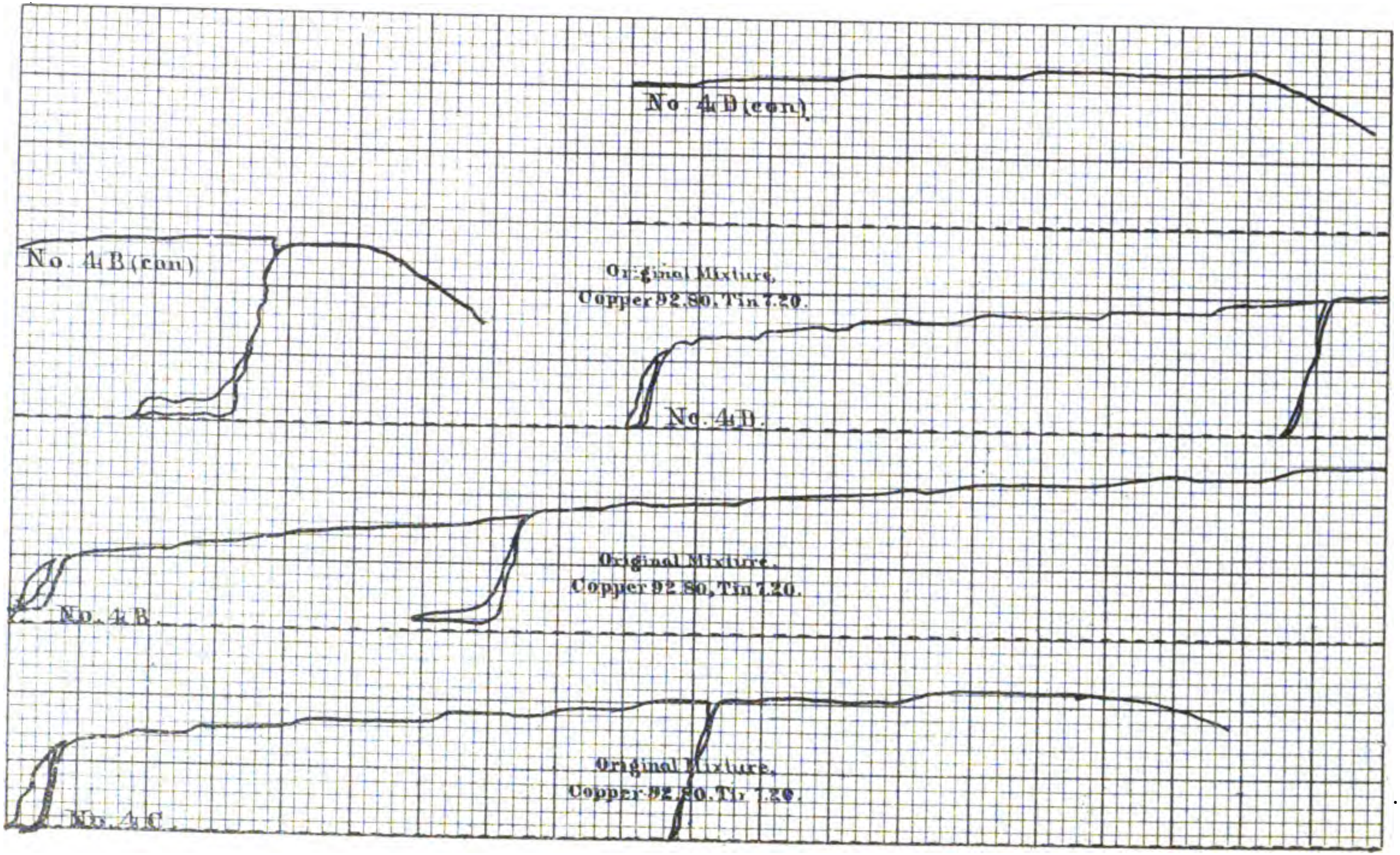
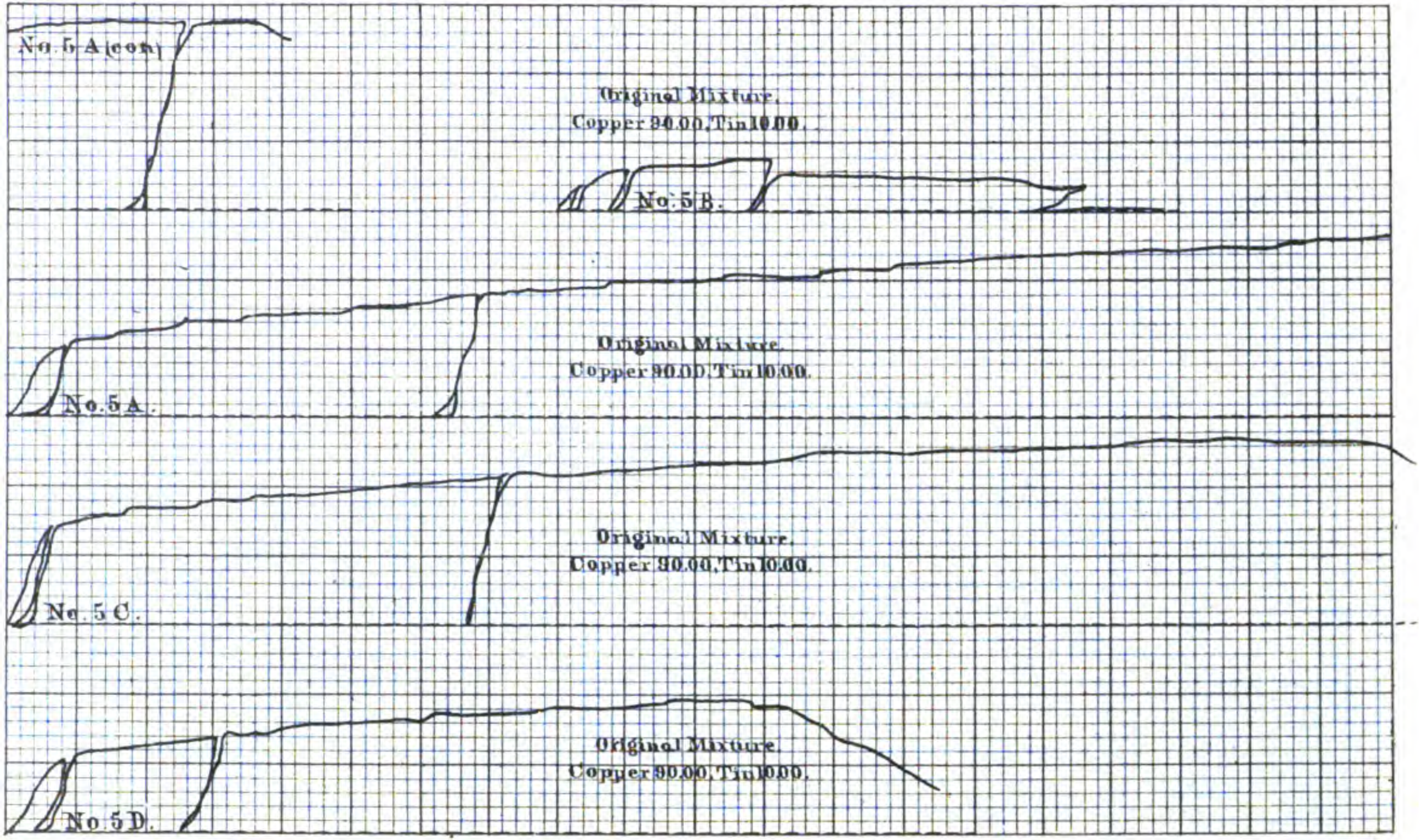
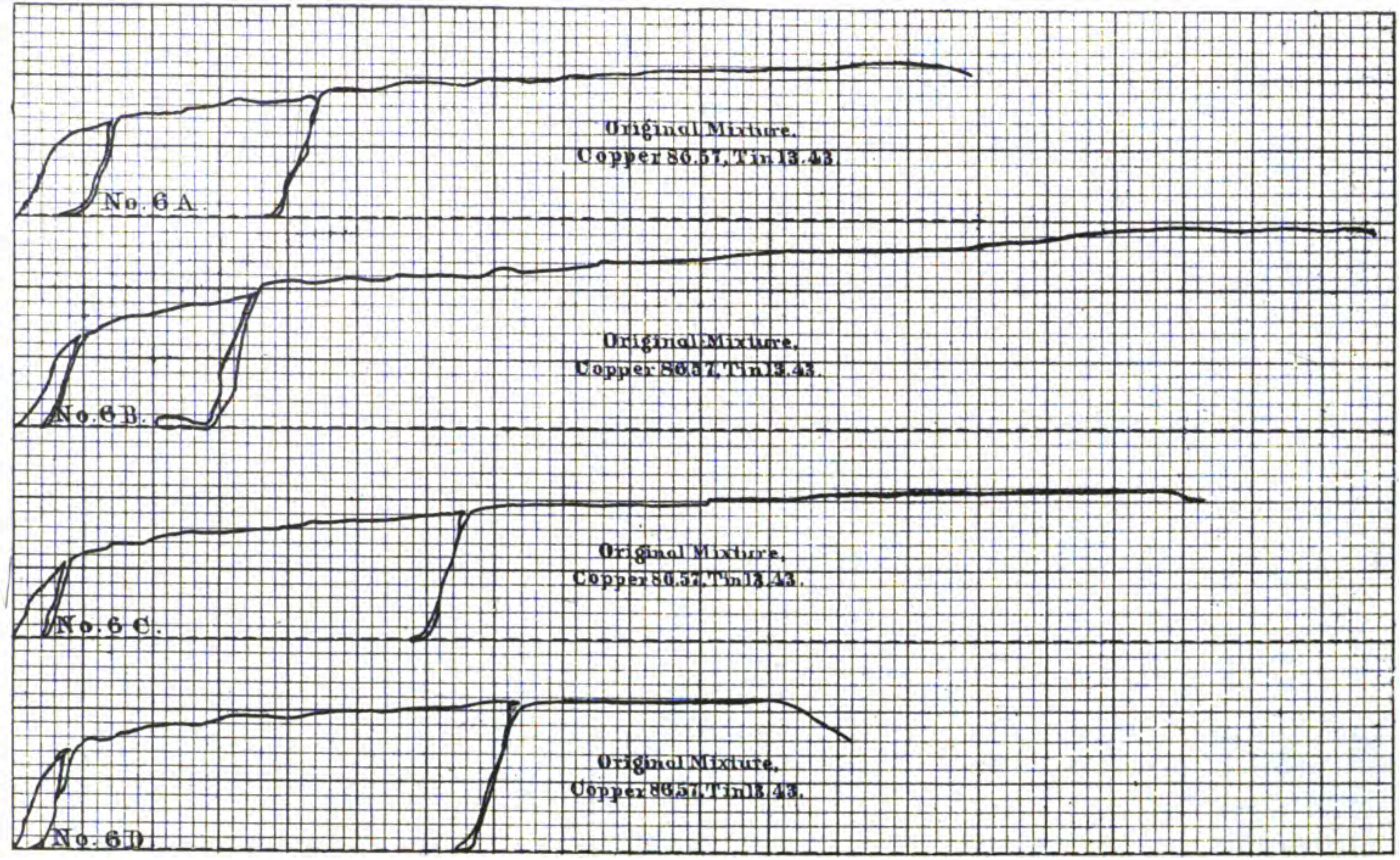


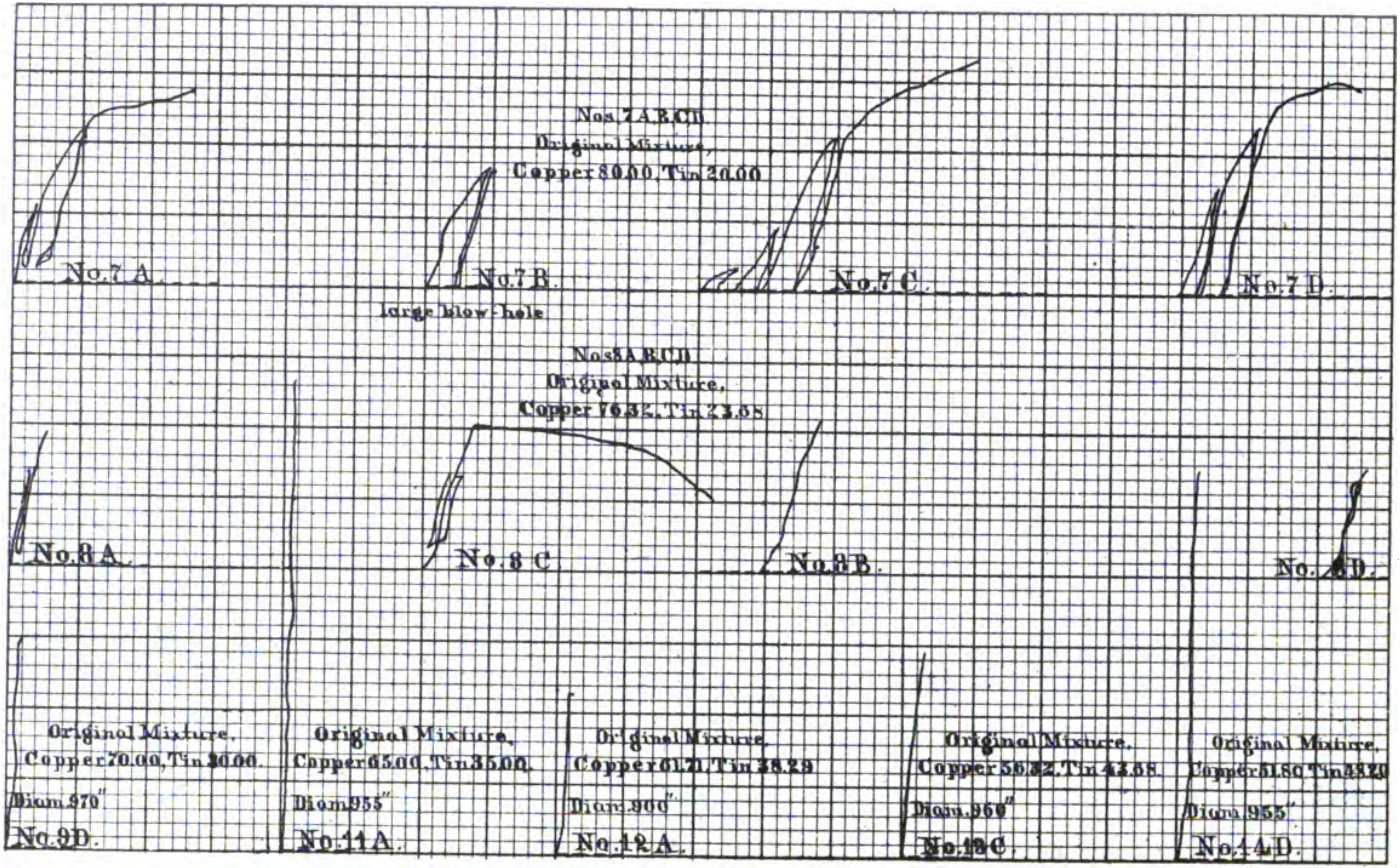
PLATE XXX.

Fac-Simile Autographic Strain Diagrams.

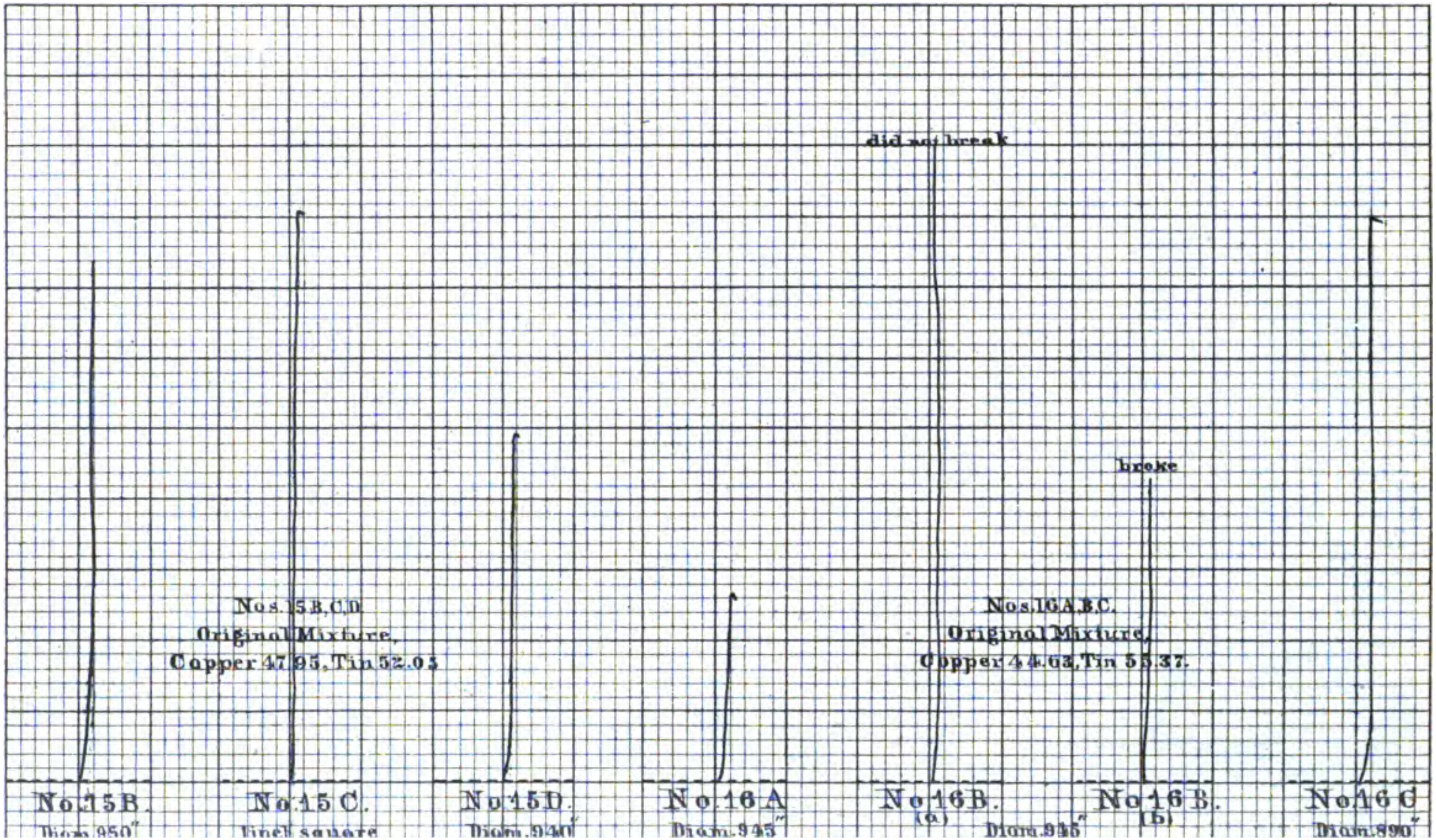


Fac-Simile Autographic Strain Diagrams.

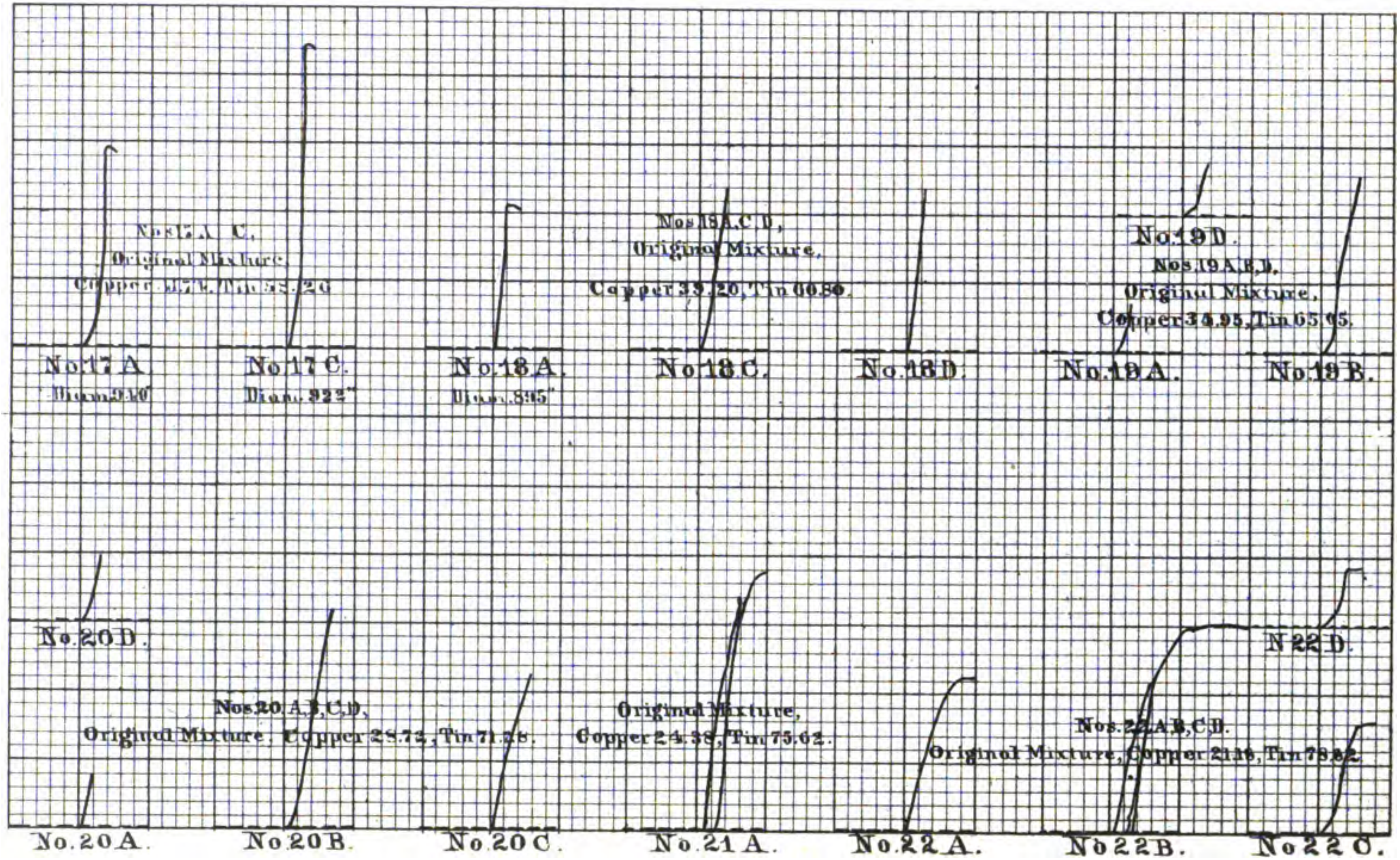



Nos. 7 A.B.C.D.
Original Mixture,
Copper 80.00, Tin 20.00
No. 7 A.
No. 7 B.
large blow-hole
No. 7 C.
No. 7 D.
Nos. 8 A.B.C.D.
Original Mixture,
Copper 76.32, Tin 23.68
No. 8 A.
No. 8 C.
No. 8 B.
No. 8 D.
Original Mixture,
Copper 70.00, Tin 30.00.
Diam. 970"
No. 9 D.
Original Mixture,
Copper 65.00, Tin 35.00.
Diam. 955"
No. 11 A.
Original Mixture,
Copper 61.71, Tin 38.29
Diam. 900"
No. 12 A.
Original Mixture,
Copper 56.32, Tin 43.68.
Diam. 960"
No. 13 C.
Original Mixture,
Copper 51.80 Tin 48.20
Diam. 955"
No. 14 D.

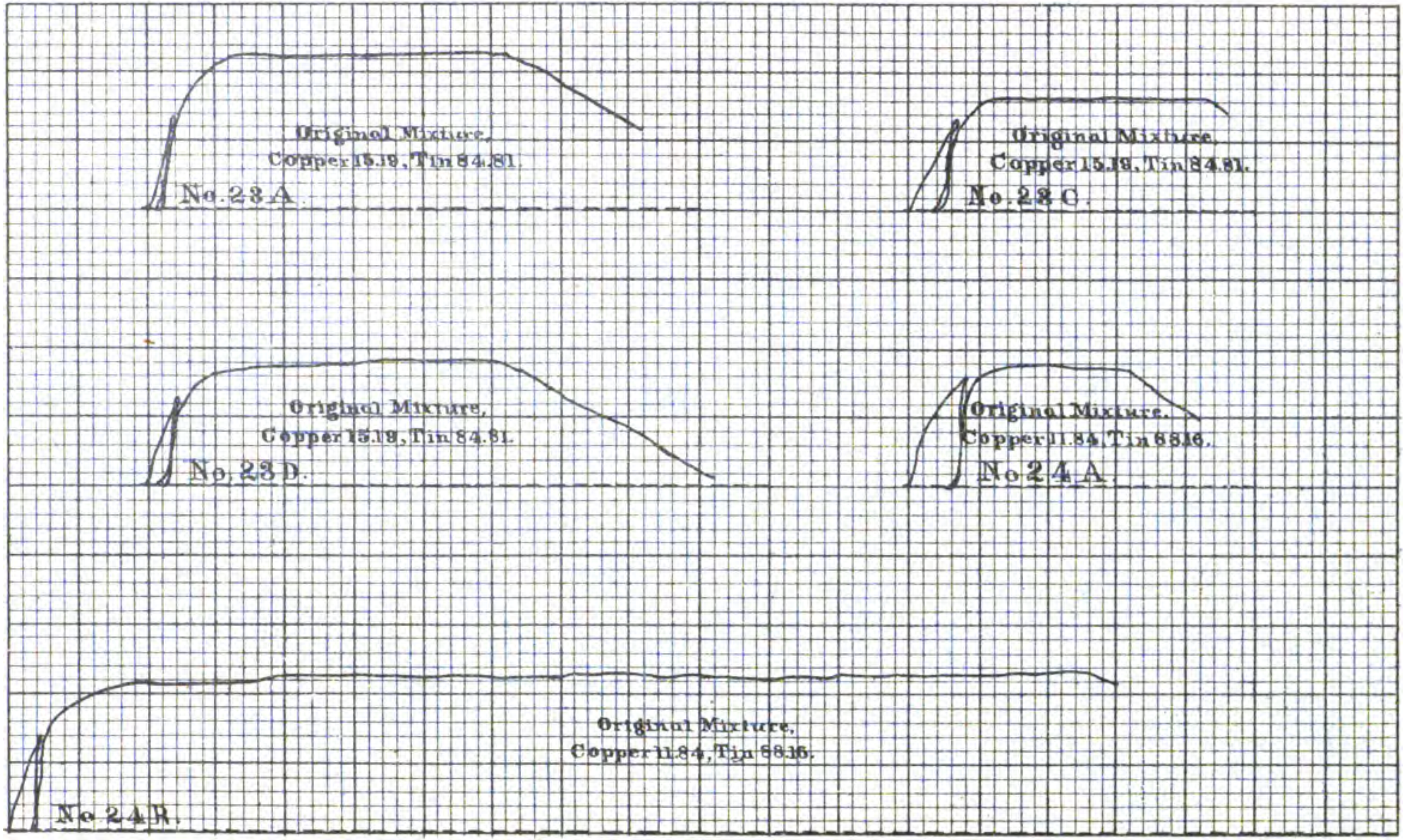
Fac-Simile Autographic Strain Diagrams.



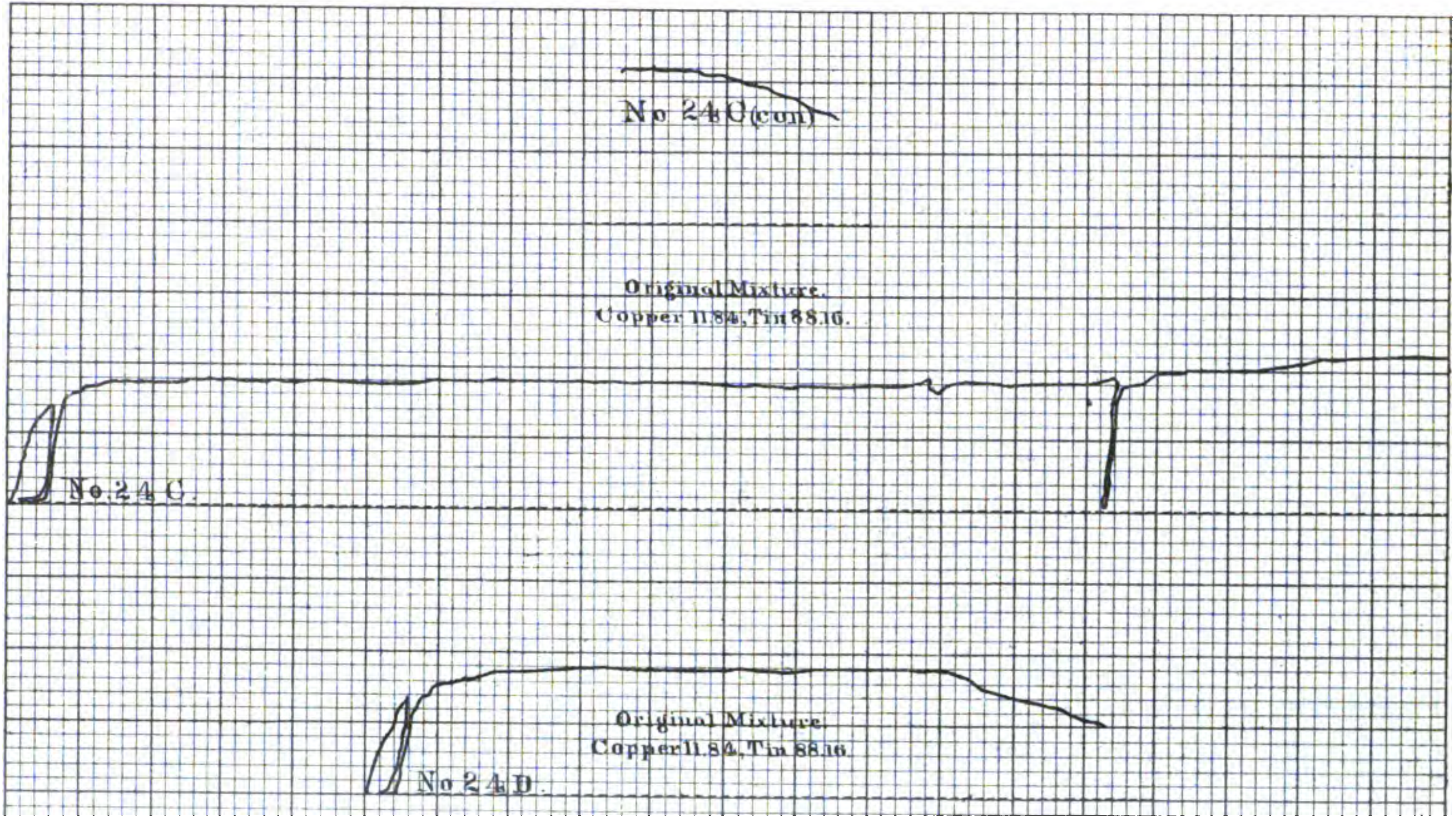
Fac-Simile Autographic Strain Diagrams.



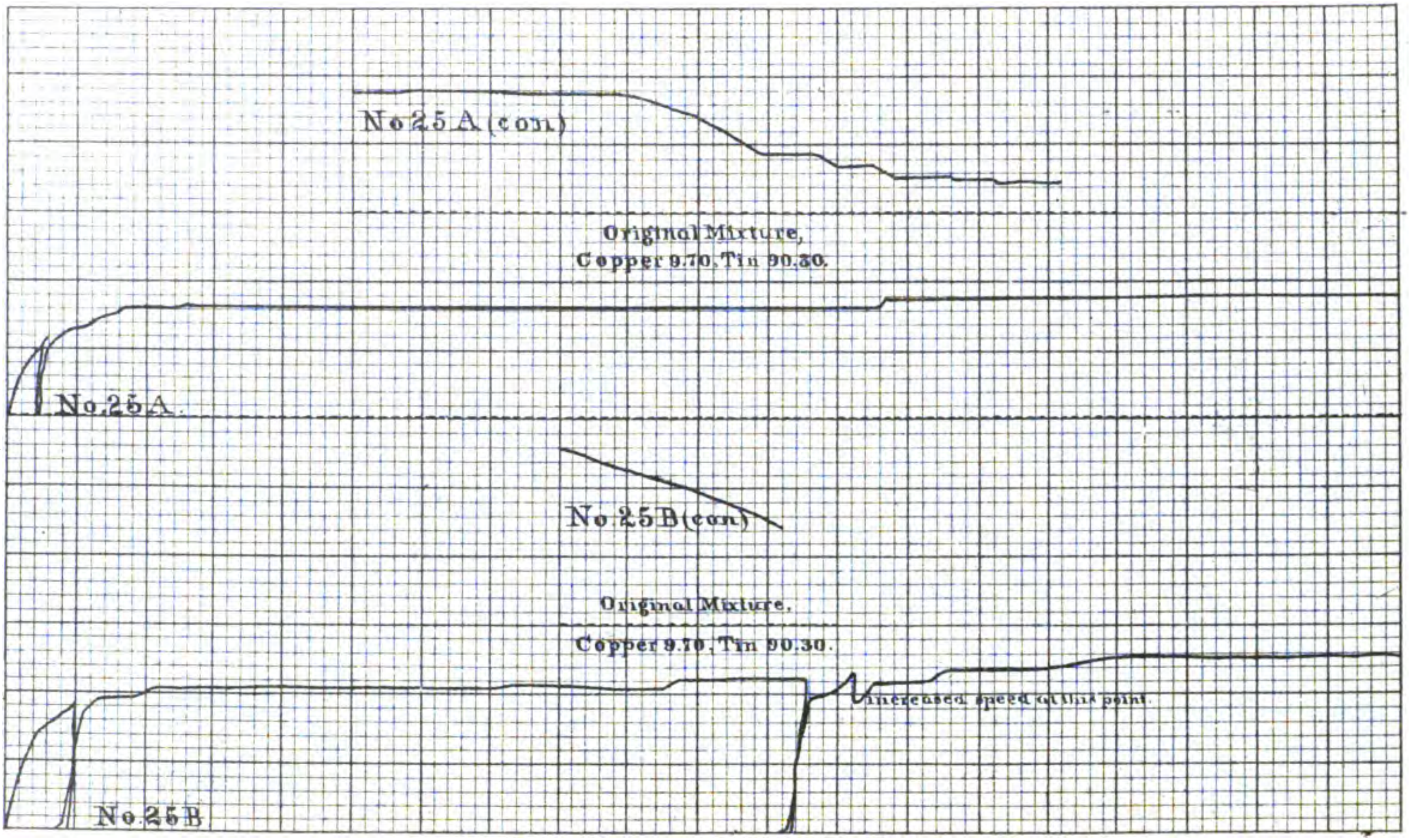
Fac-Simile Autographic Strain Diagrams.



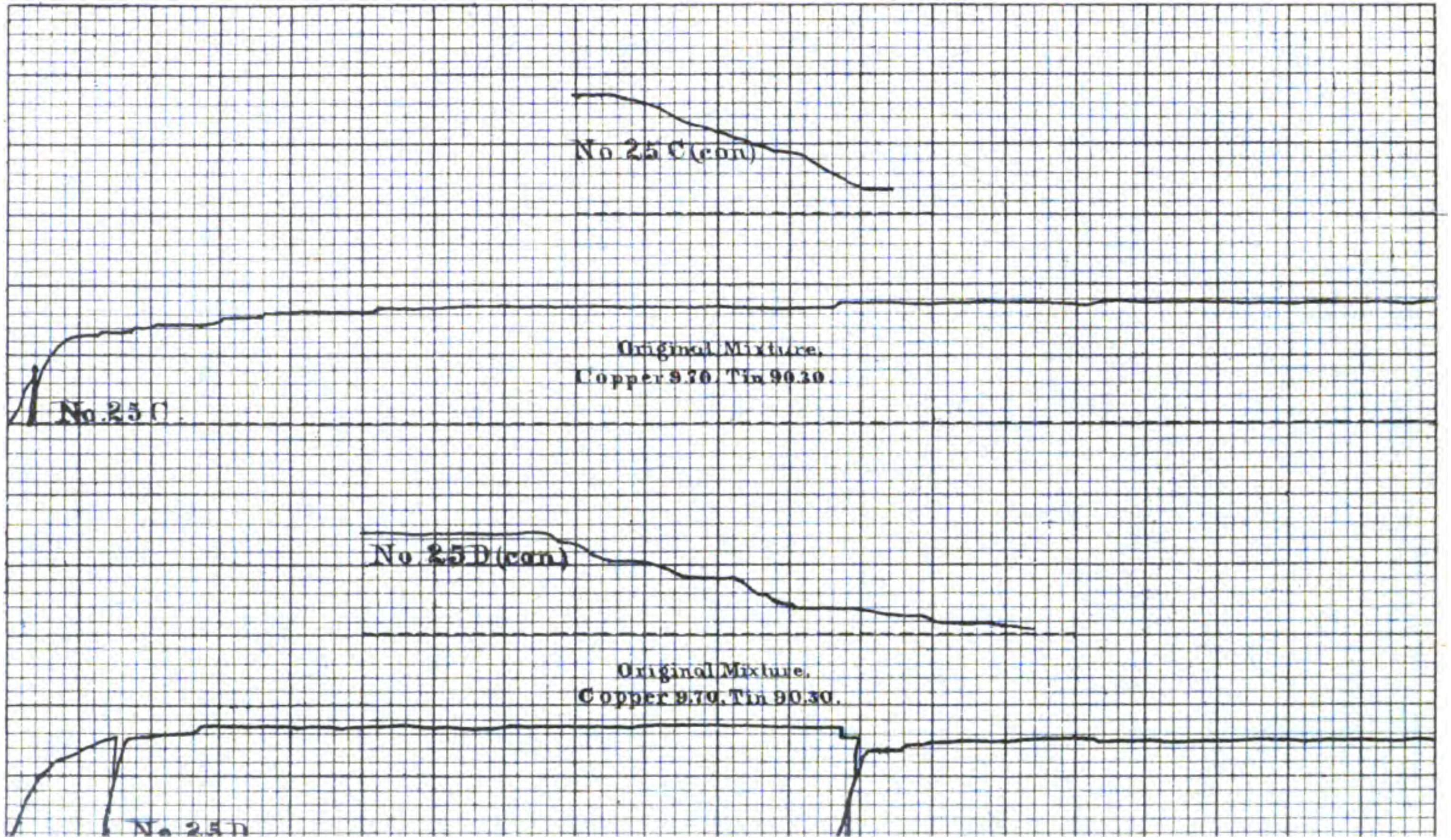
Fac-Simile Autographic Strain Diagrams.

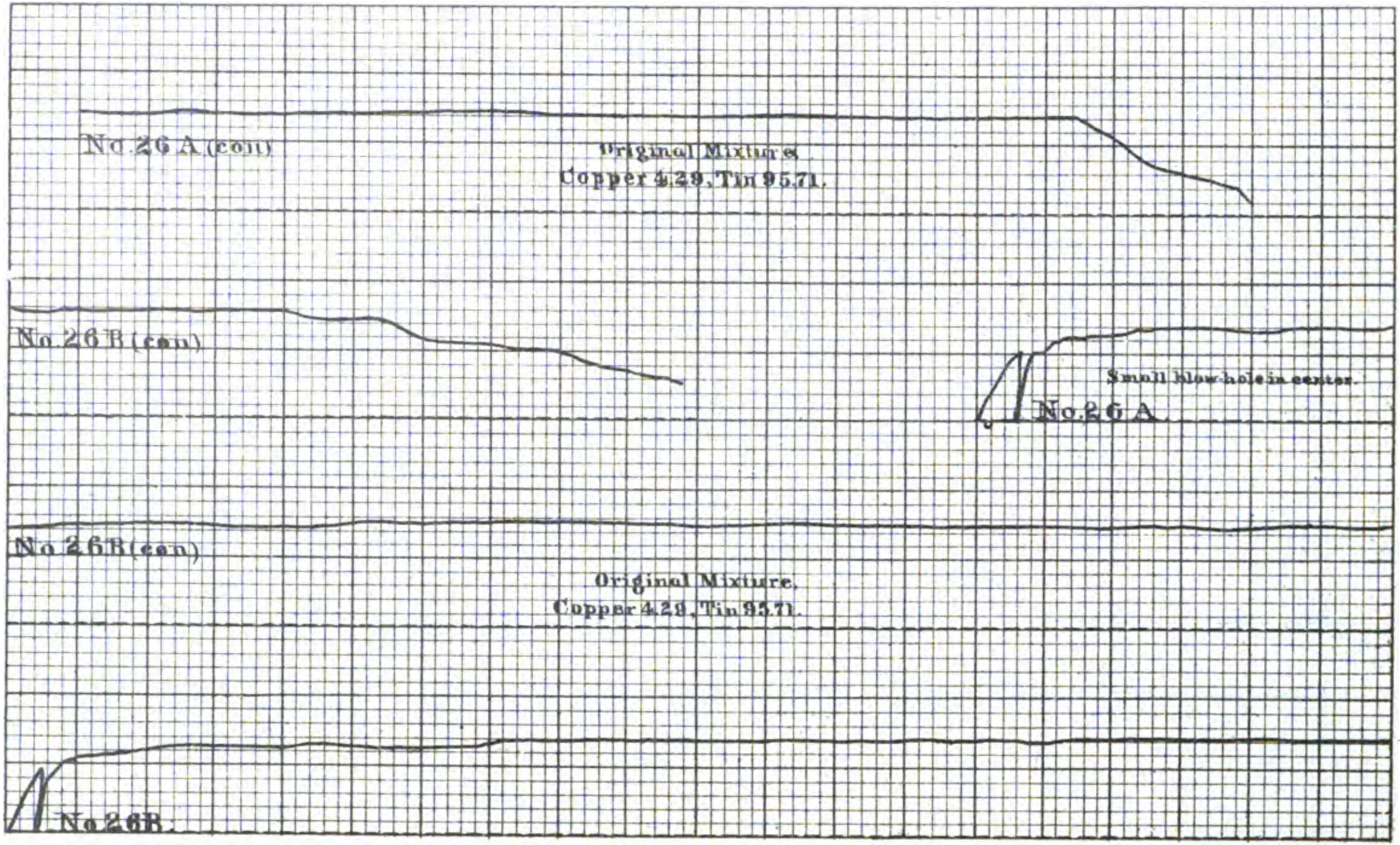


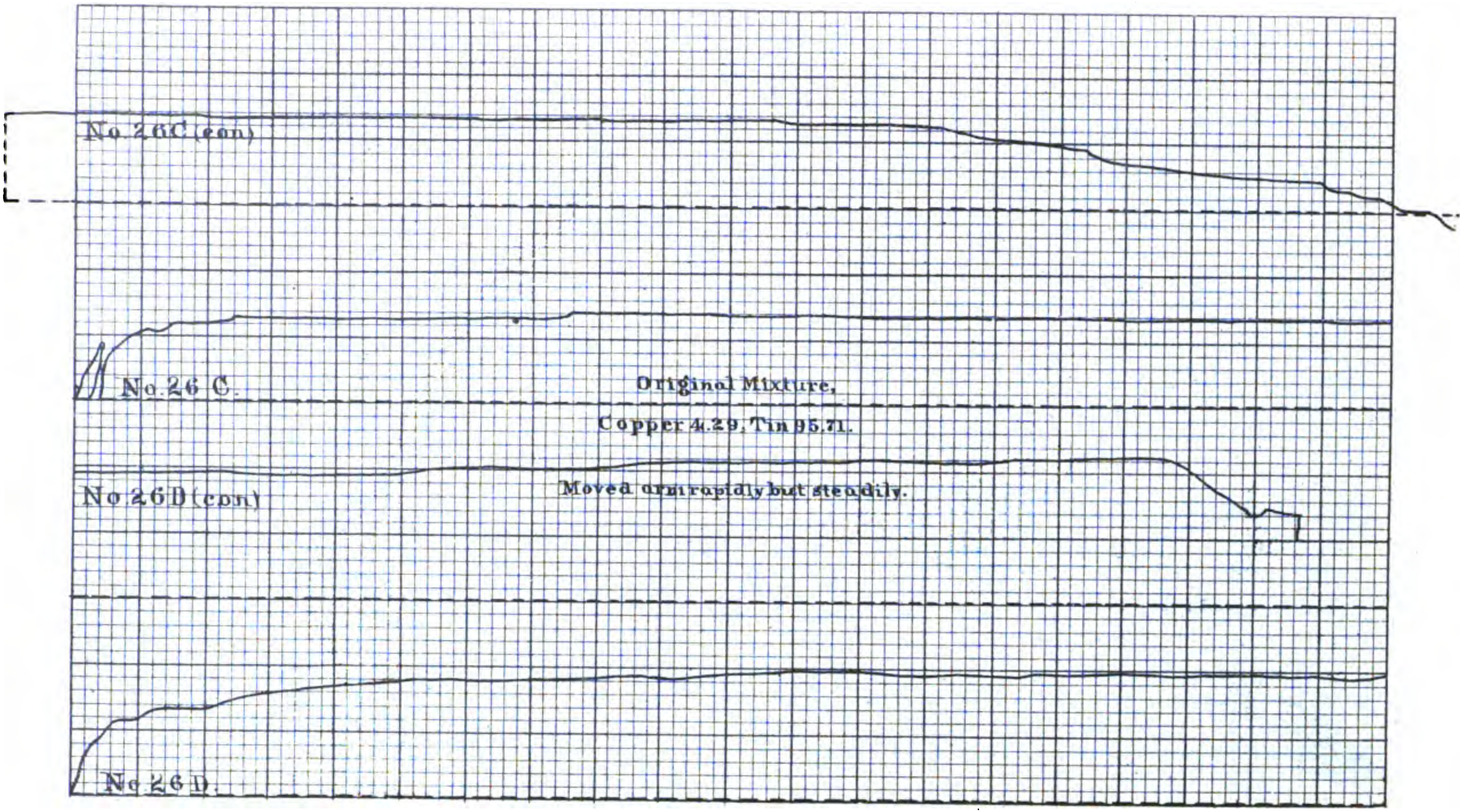
Fac-Simile Autographic Strain Diagrams.



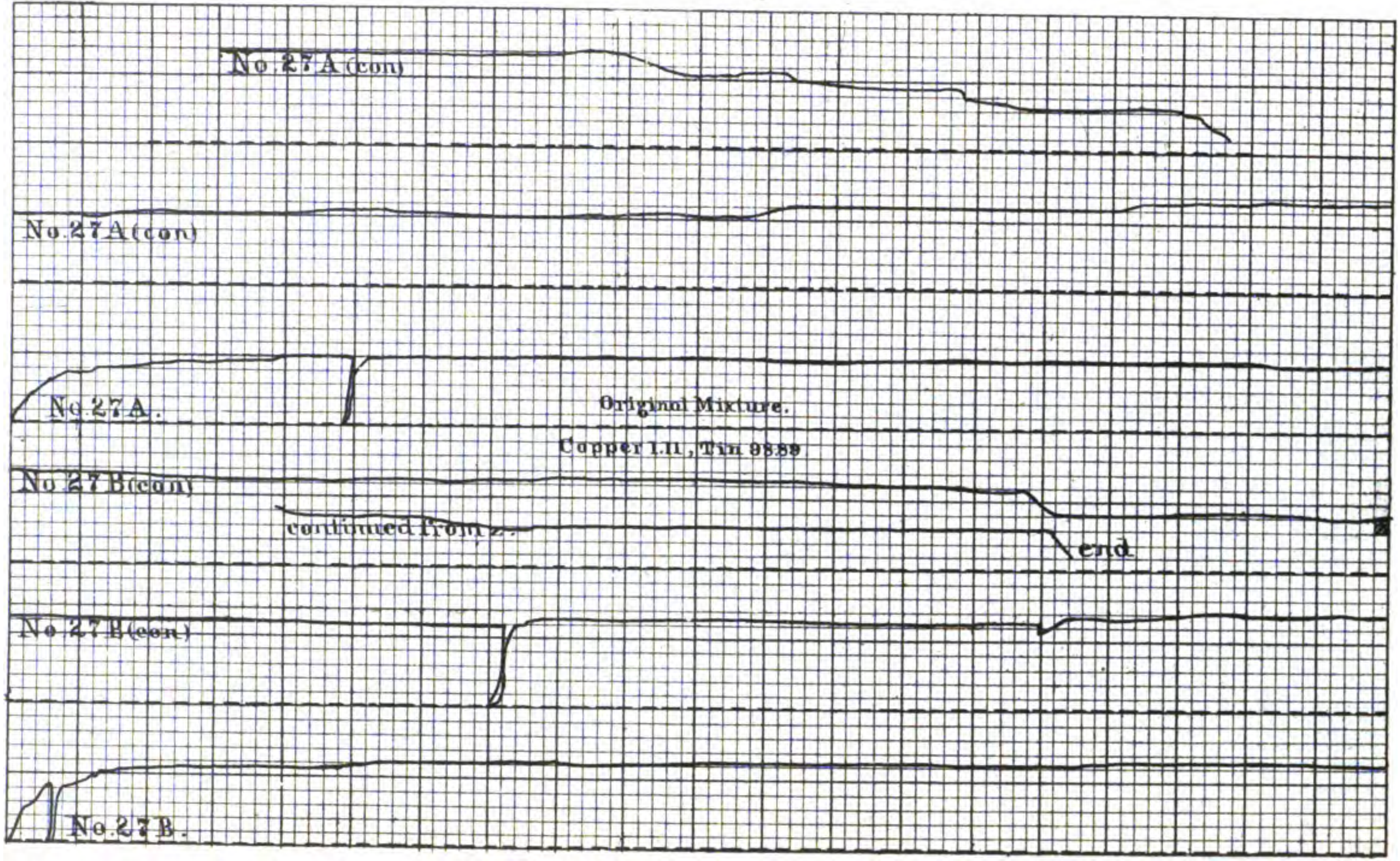
Fac-Simile Autographic Strain Diagrams.

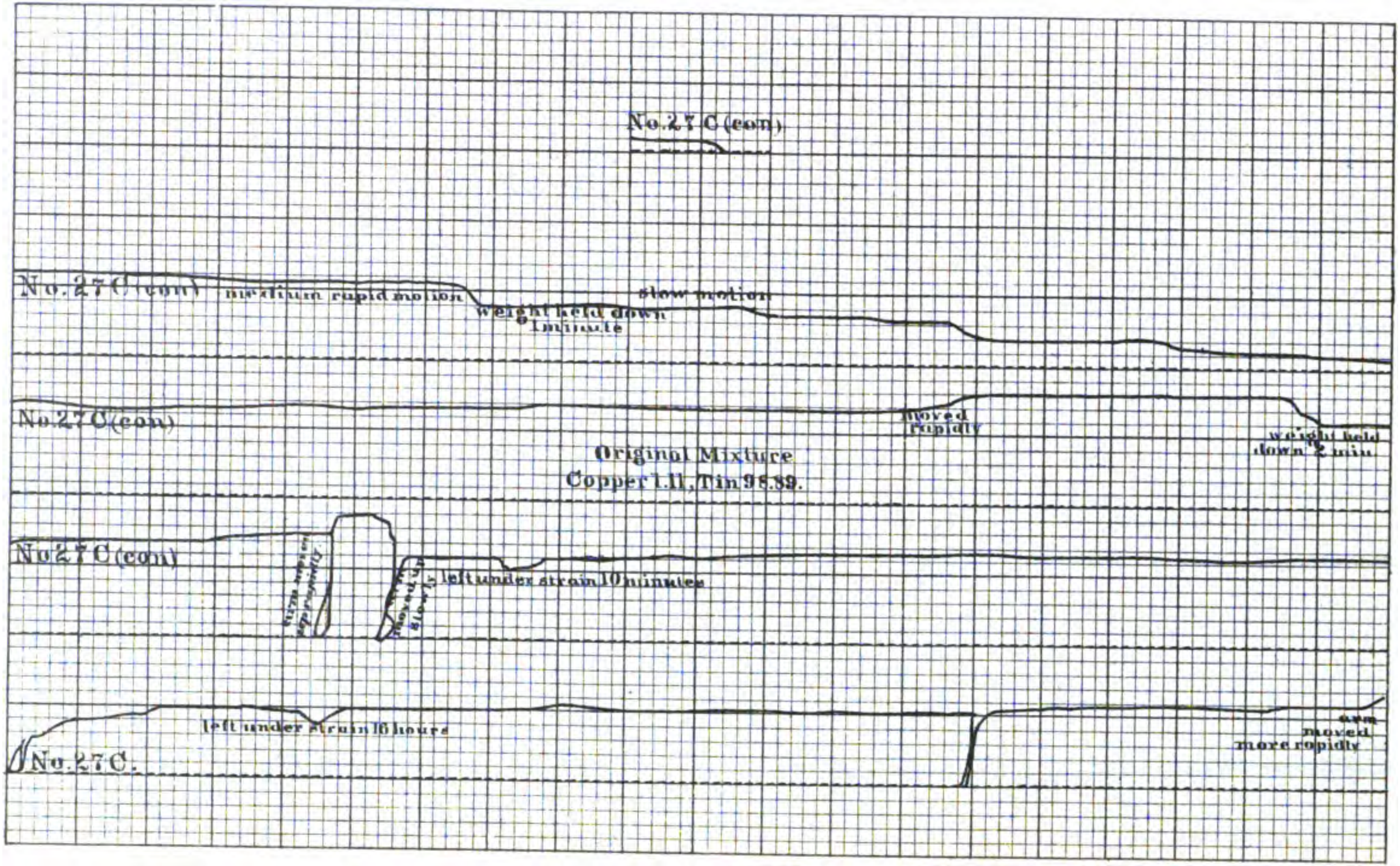



No 26 A (con)
Original Mixture
Copper 4.29, Tin 95.71.
No 26 B (con)
Small blow-hole in center.
No 26 A
No 26 B (con)
Original Mixture.
Copper 4.29, Tin 95.71.
No 26 B.

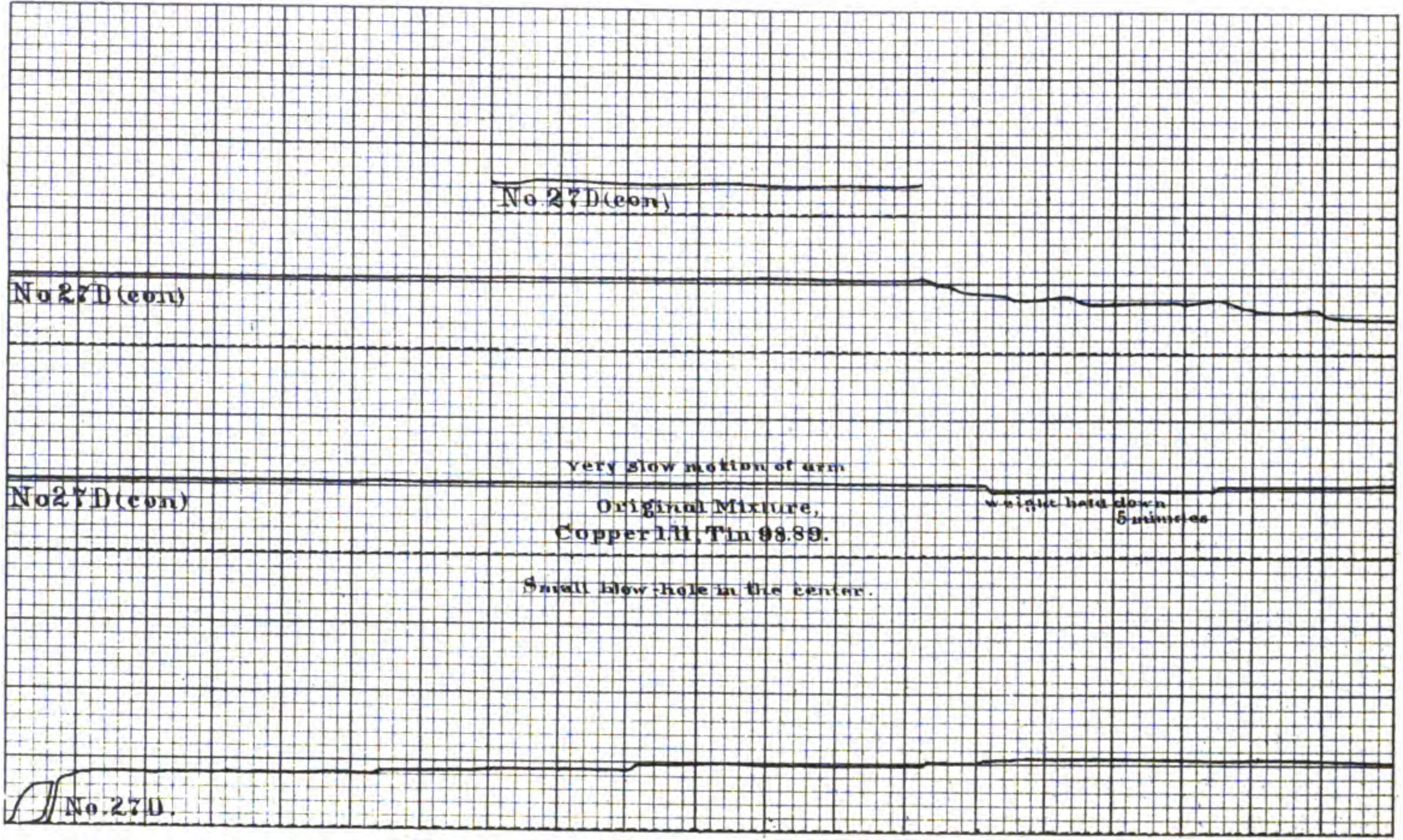

No. 26C (con)
No. 26 C.
Original Mixture,
Copper 4.29, Tin 95.71.
No. 26D (con)
Moved arm rapidly but steadily.
No. 26 D.

Fac-Simile Autographic Strain Diagrams.



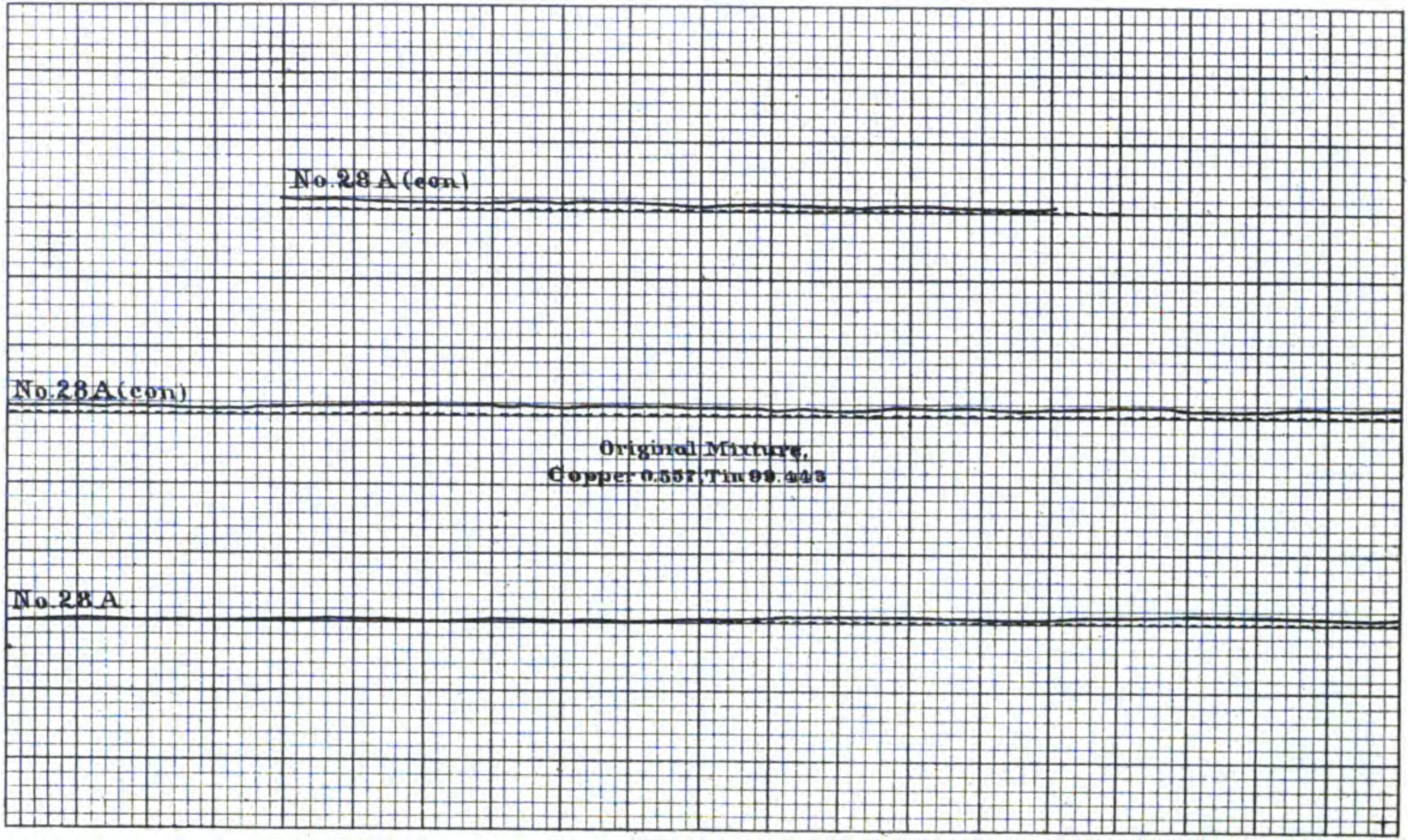


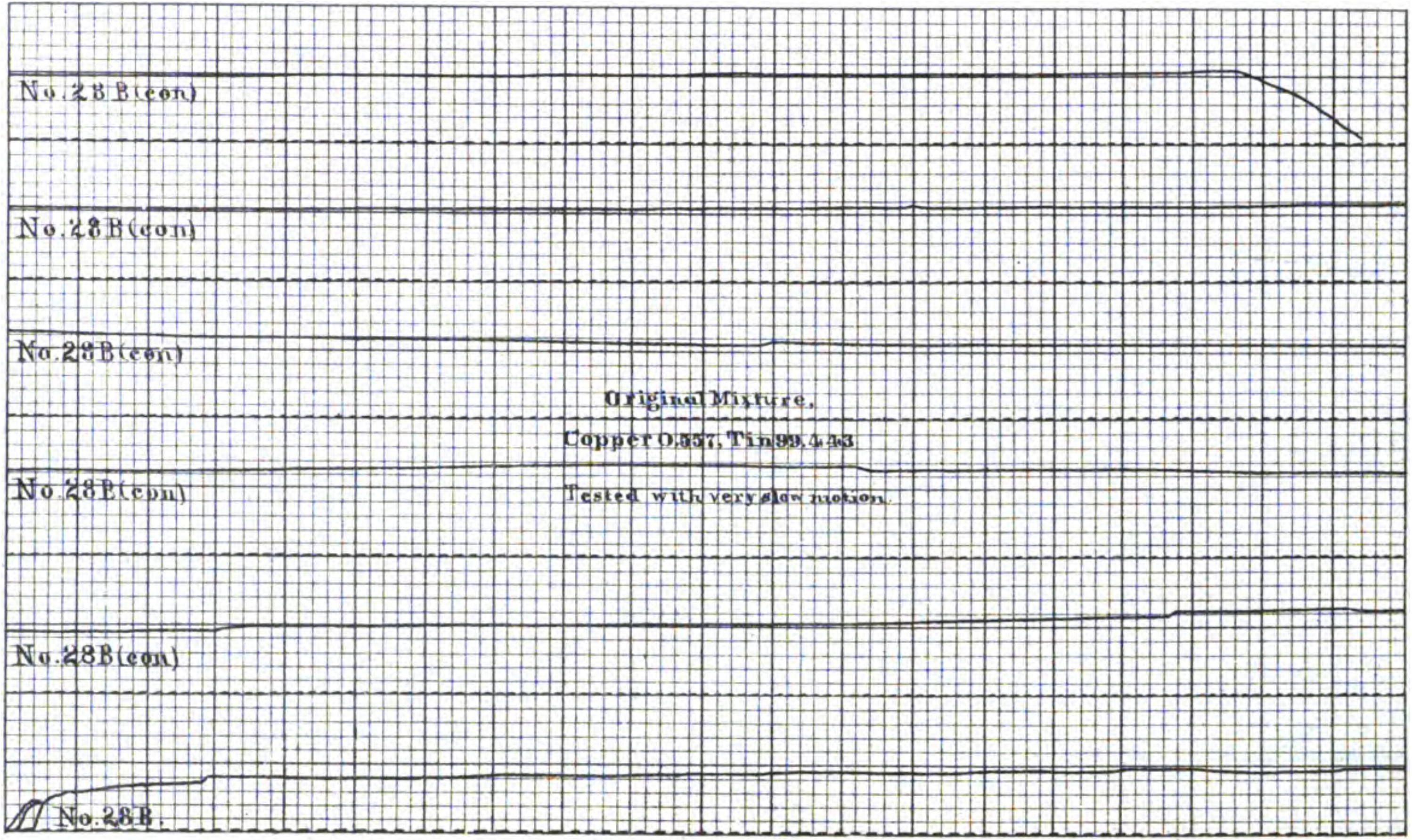
No.27 C (con)
No.27 C (con)
medium rapid motion
weight held down 1 minute
slow motion
No.27 C (con)
moved rapidly
weight held down 2 min.
Original Mixture
Copper 1.11, Tin 98.89.
No.27 C (con)
arm moved rapidly
arm moved slowly
left under strain 10 minutes
No.27 C.
left under strain 16 hours
arm moved more rapidly



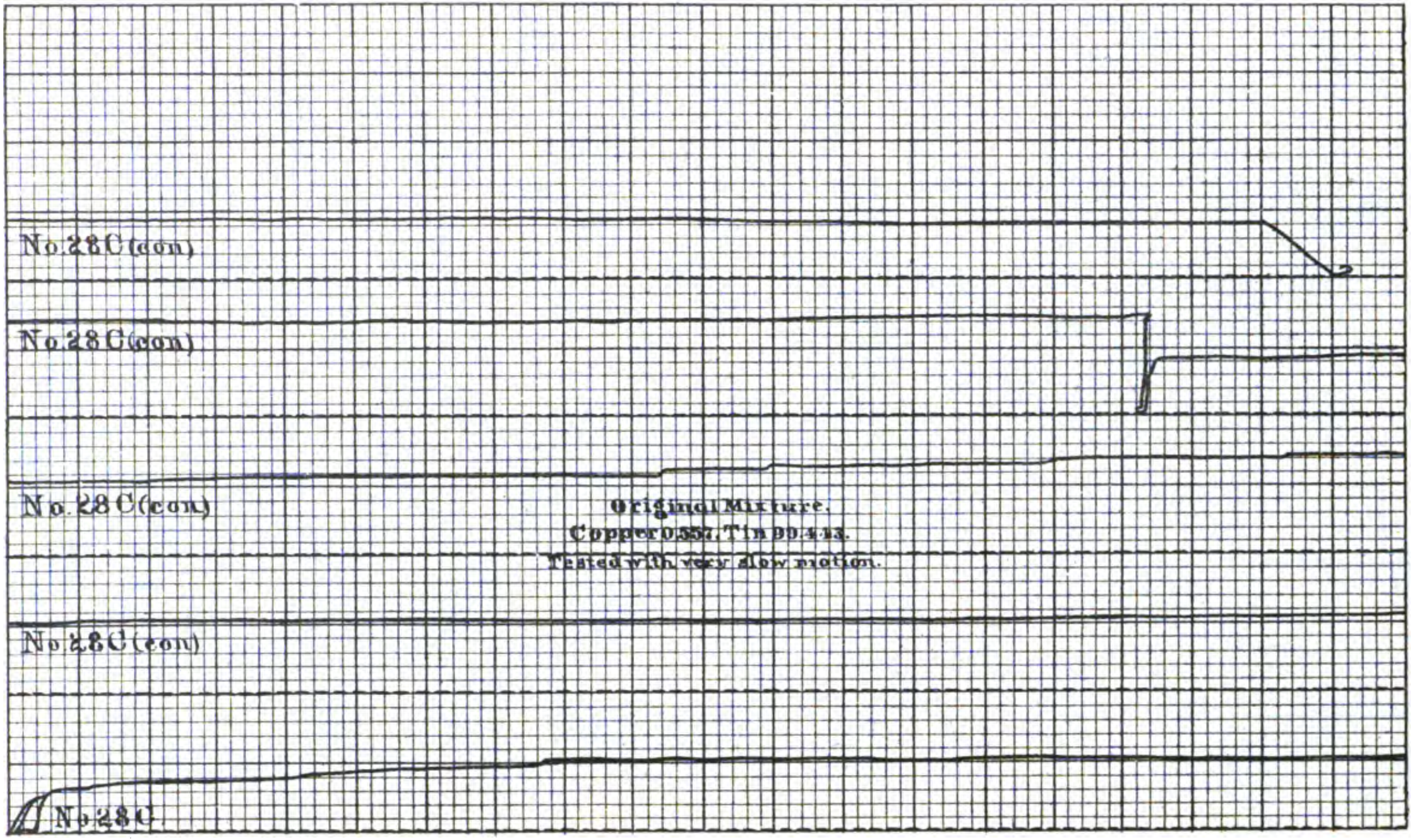
Original Mixture,
Copper 1.11, Tin 98.89.

Small blow-hole in the center.


No. 28 A (con)
No. 28 A (con)
Original Mixture,
Copper 0.557, Tin 99.443
No. 28 A

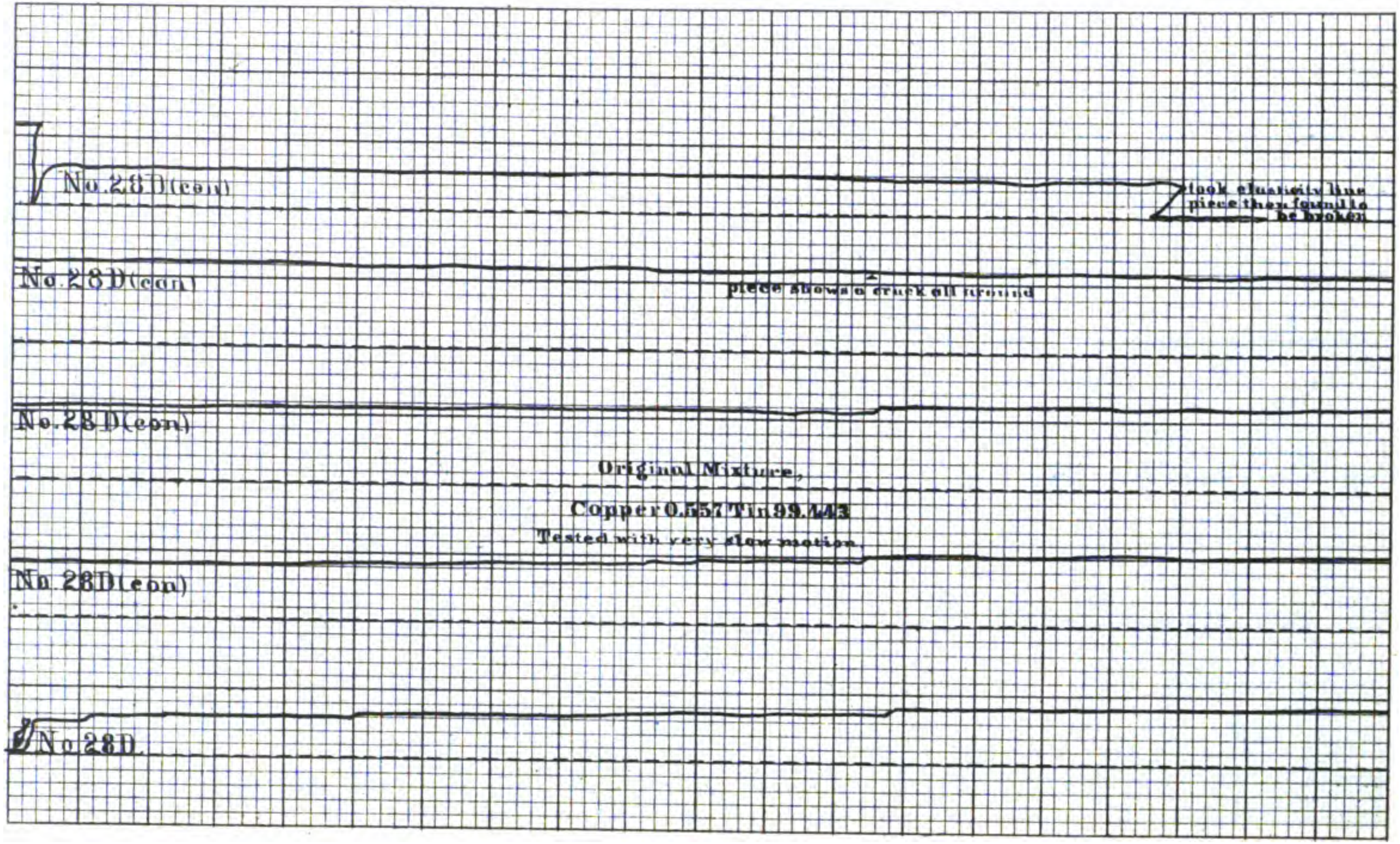

No. 28 B (con)
No. 28 B (con)
No. 28 B (con)
Original Mixture,
Copper 0.557, Tin 99.443
Tested with very slow motion.
No. 28 B (con)
No. 28 B (con)
No. 28 B.

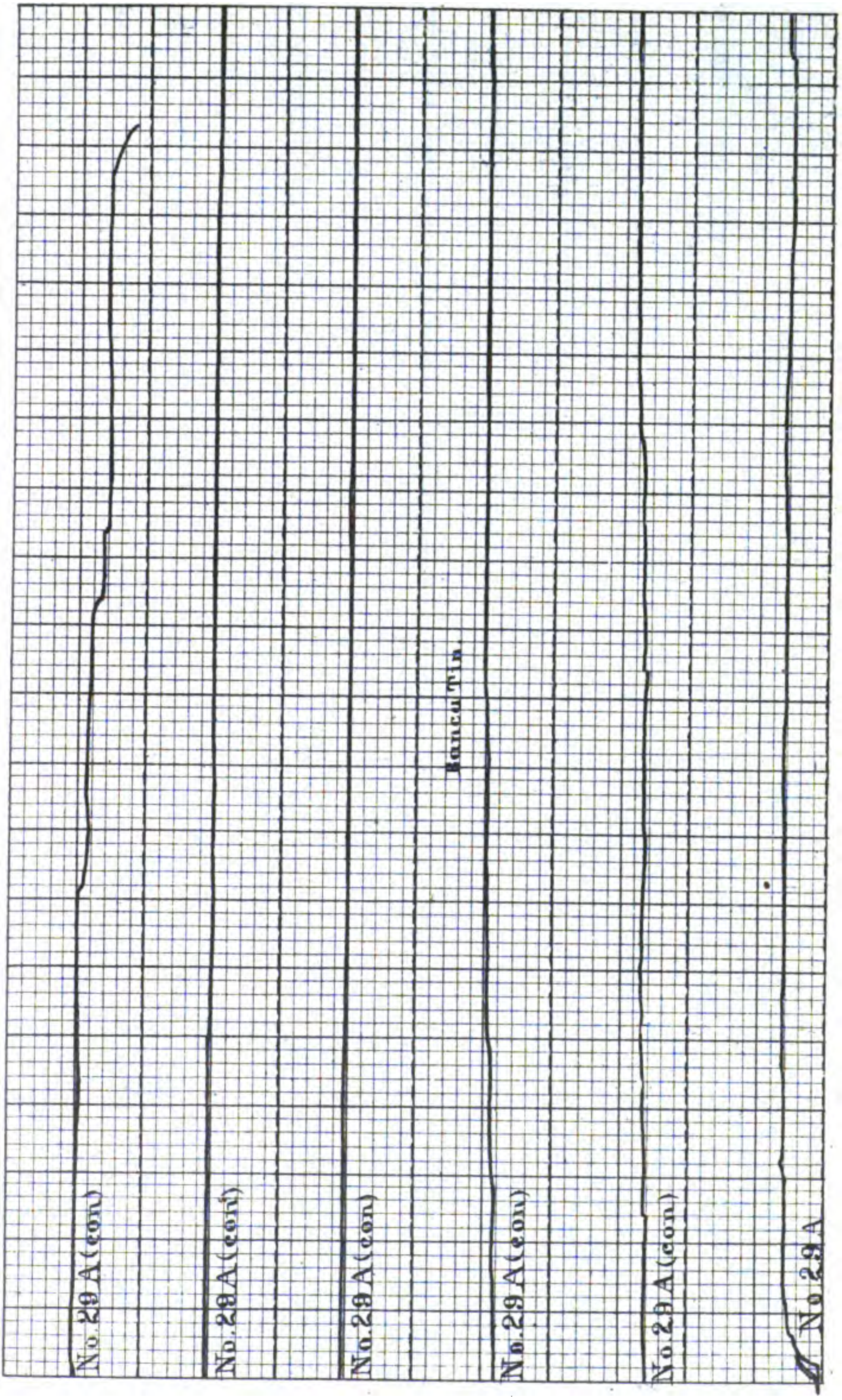
Fac-Simile Autographic Strain Diagrams.

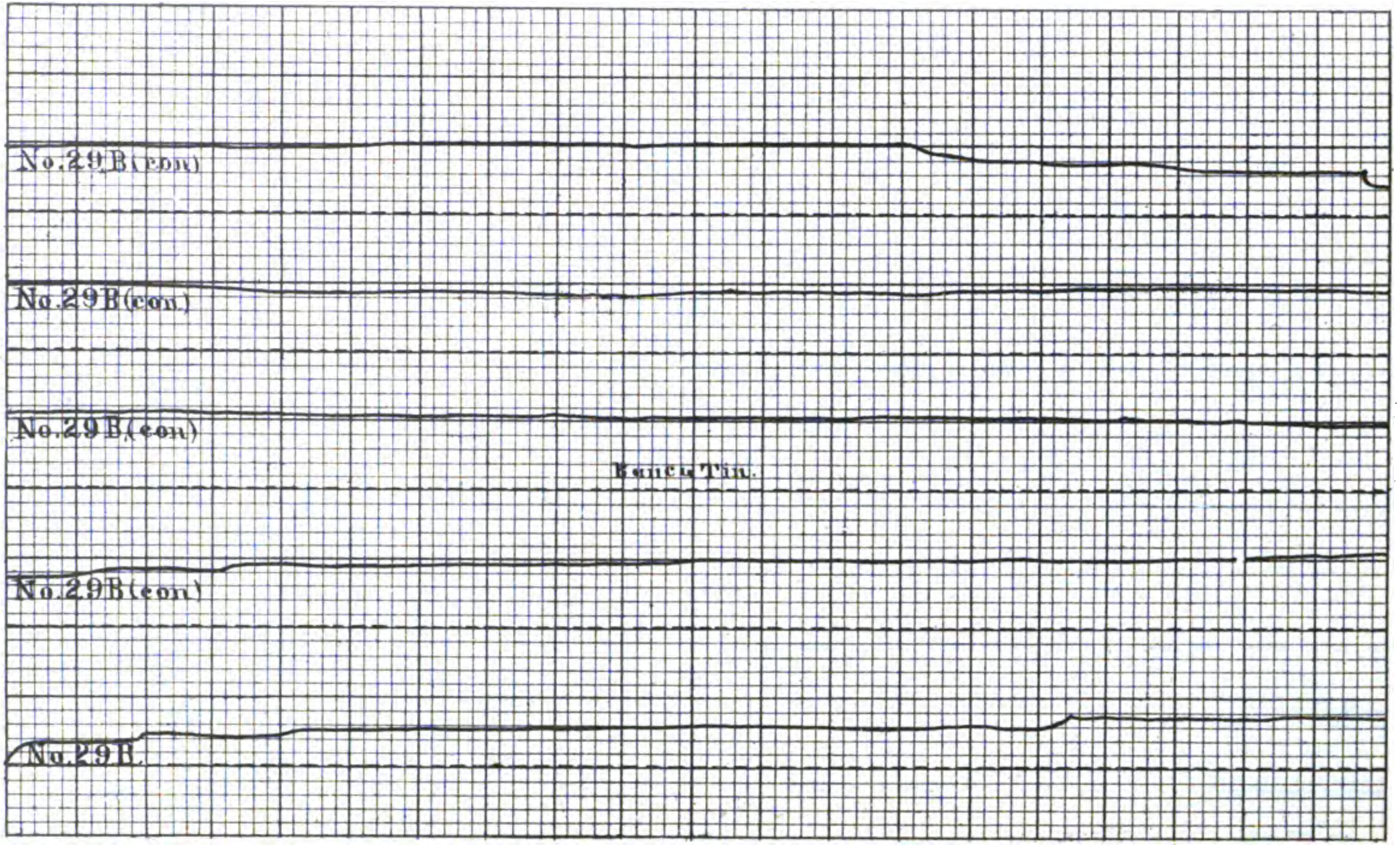


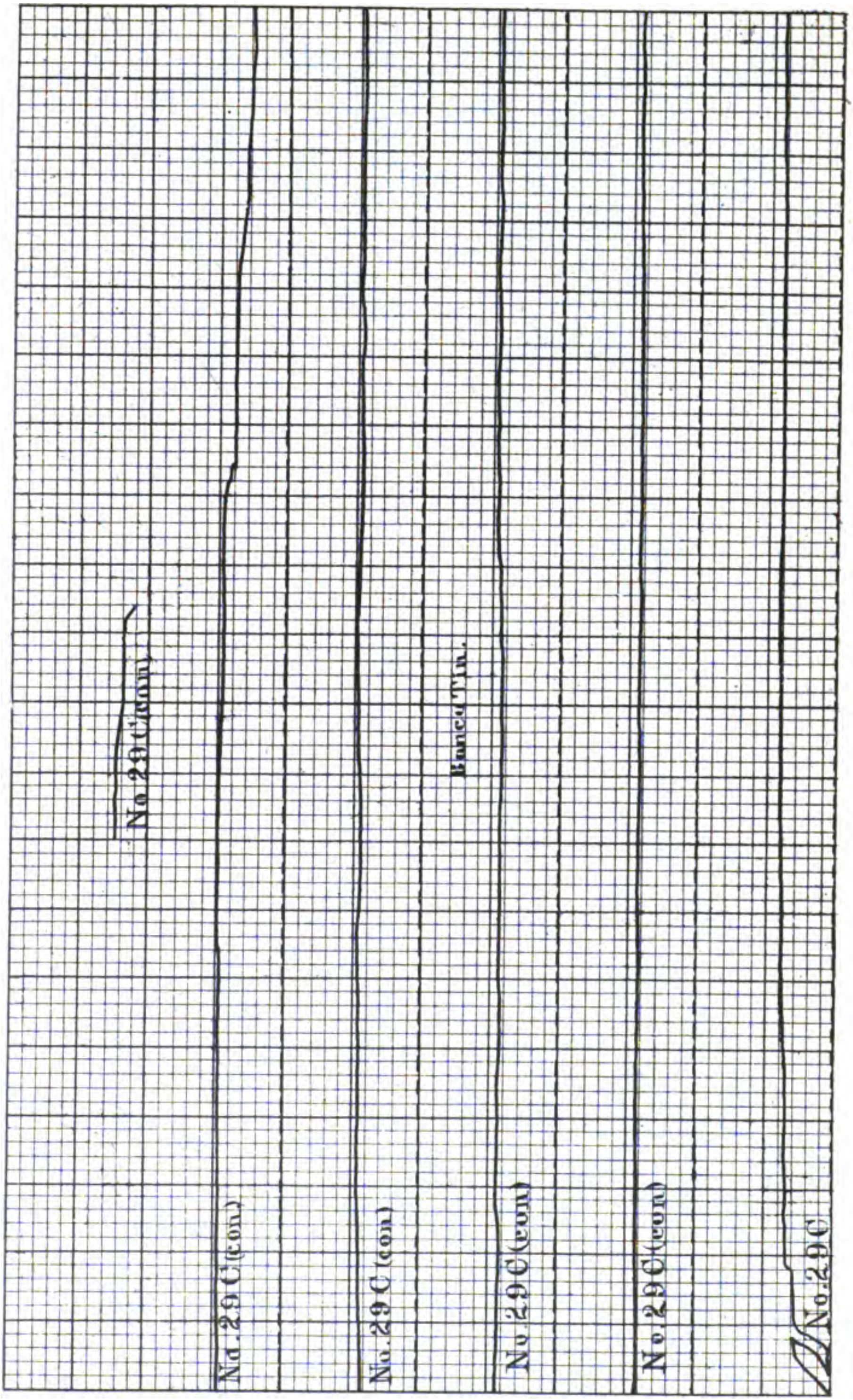
Original Mixture.
Copper 0.557, Tin 99.443.
Tested with very slow motion.

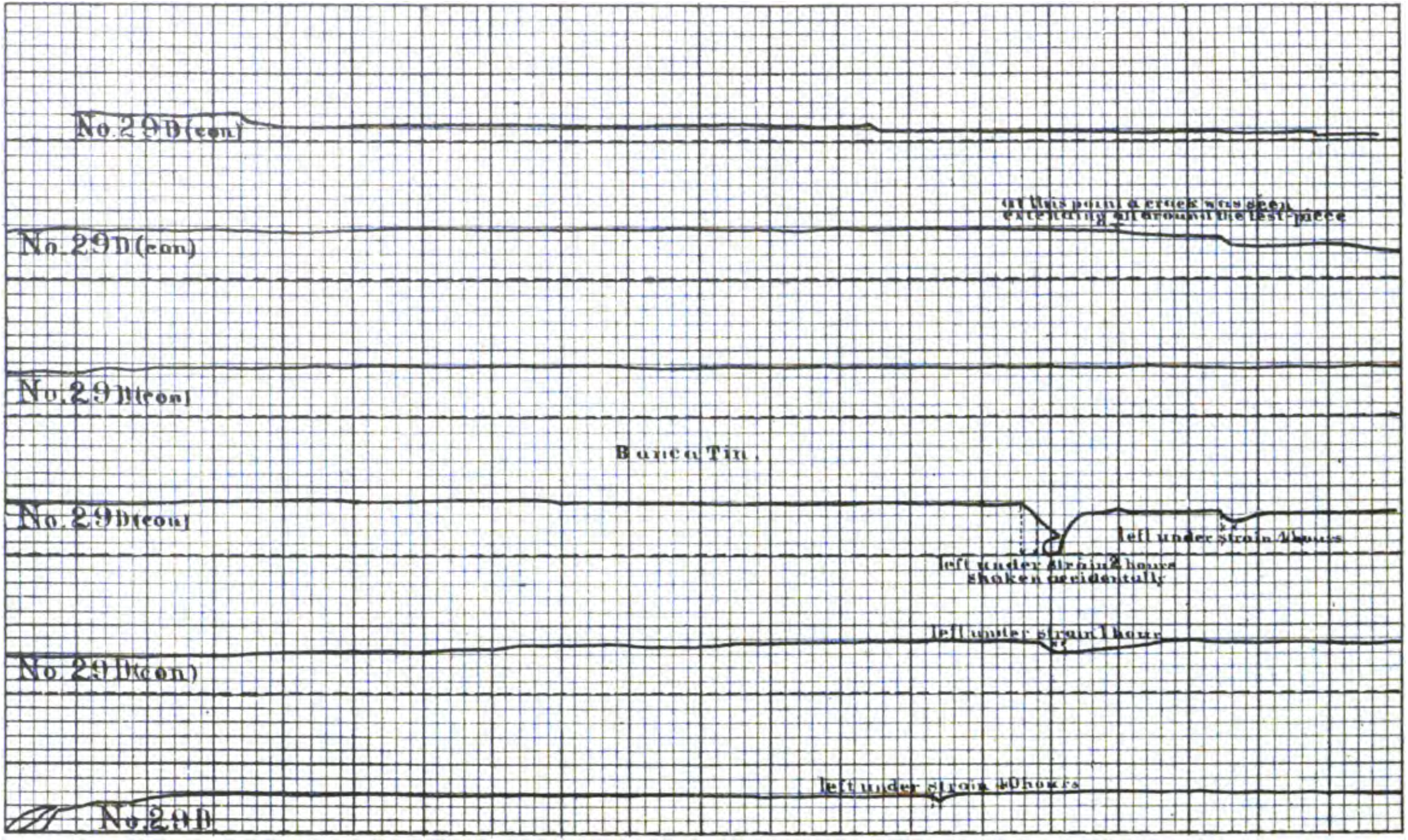
Fac-Simile Autographic Strain Diagrams.



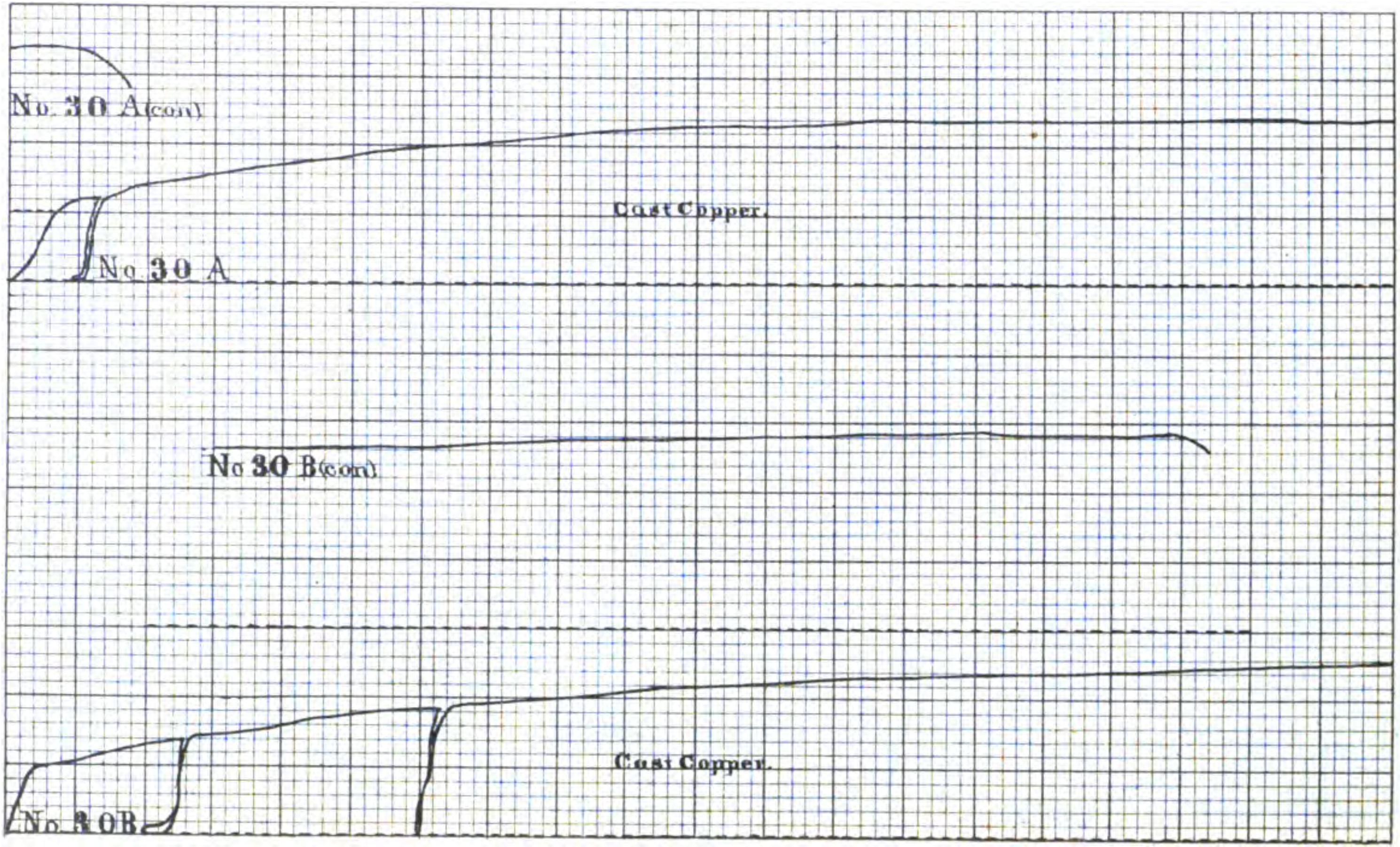

No. 29 A (con)
No. 29 A (con)
No. 29 A (con)
Banca Tin.
No. 29 A (con)
No. 29 A (con)
No. 29 A

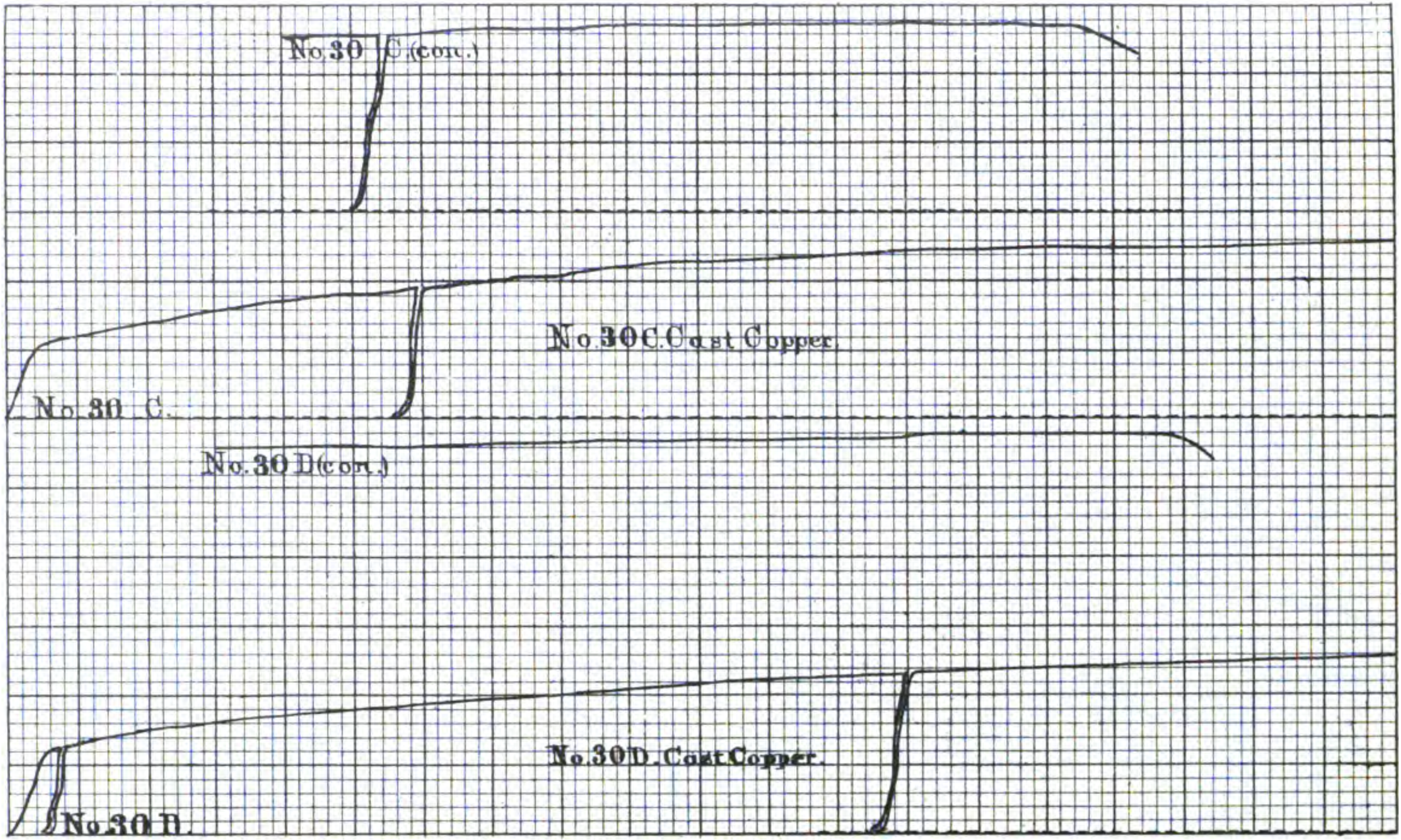

No.29B(con)
No.29B(con)
No.29B(con)
Banca Tin.
No.29B(con)
No.29B.

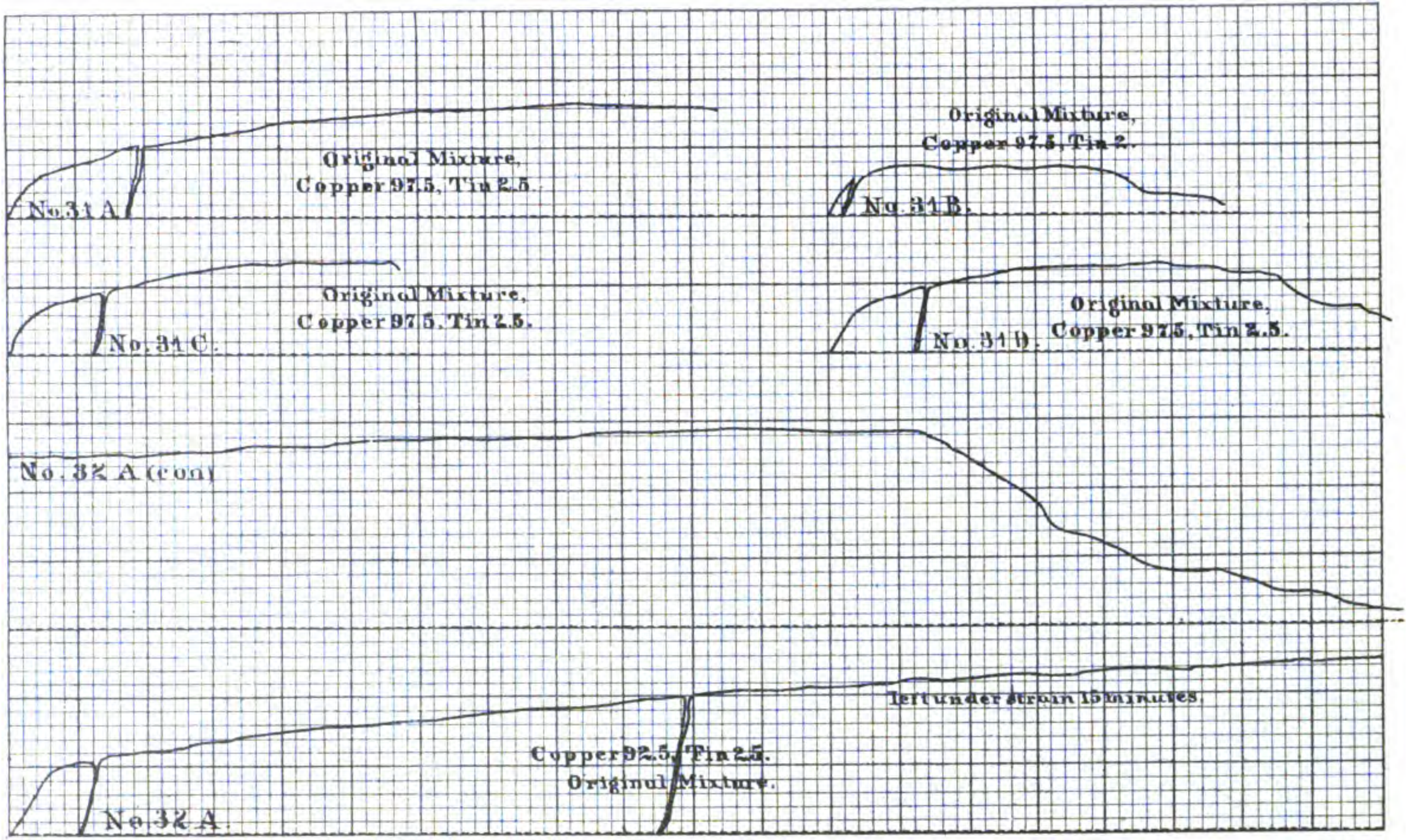

No. 29 C
No. 29 C (con)
No. 29 C (con)
Banca Tin.
No. 29 C (con)
No. 29 C (con)
No 29 C (con)

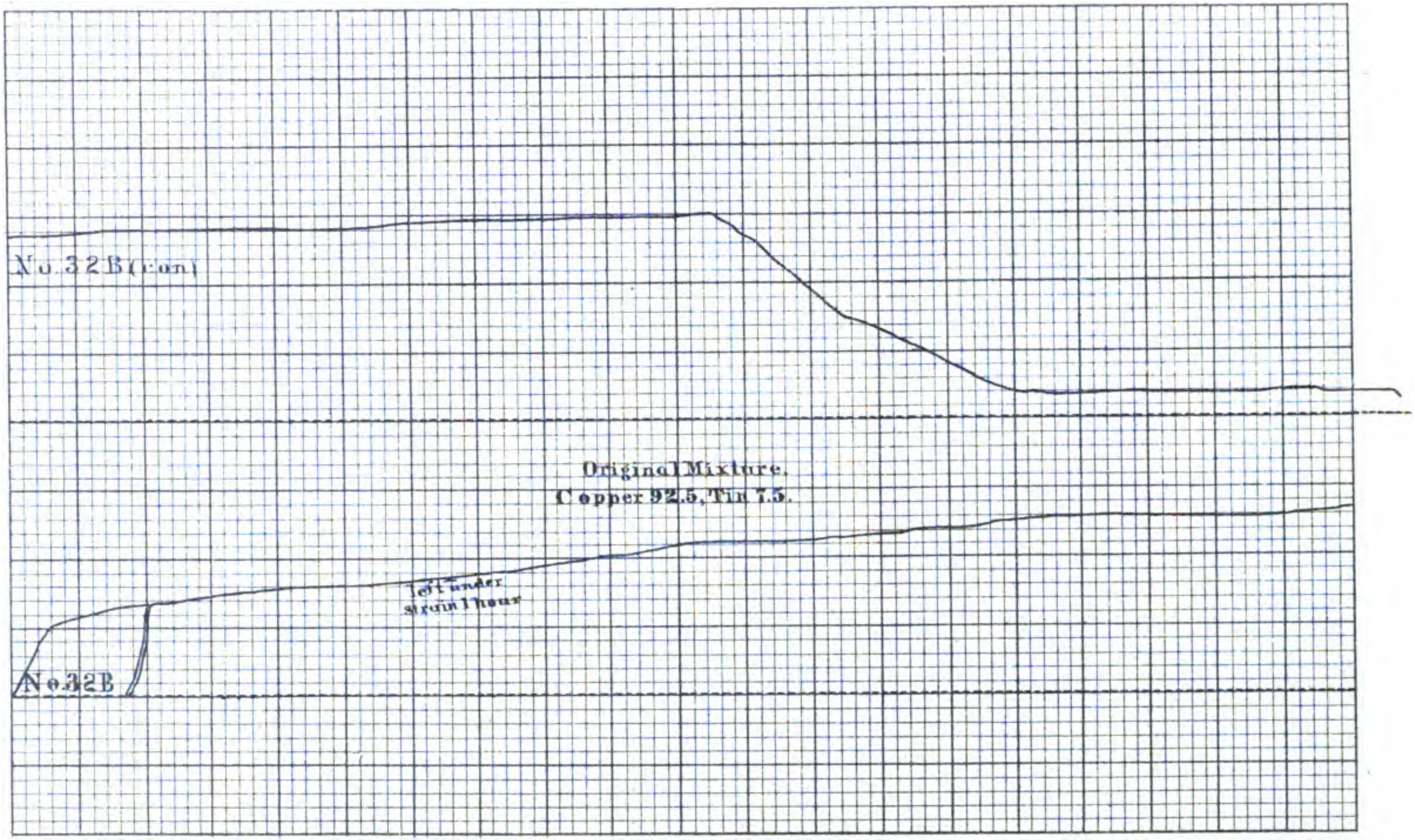

No. 29 D (con)
at this point a crack was seen extending all around the test-piece
No. 29 D (con)
No. 29 D (con)
Banca Tin.
No. 29 D (con)
left under strain 4 hours
left under strain 2 hours shaken accidentally
left under strain 1 hour
No. 29 D (con)
left under strain 40 hours
No. 29 D

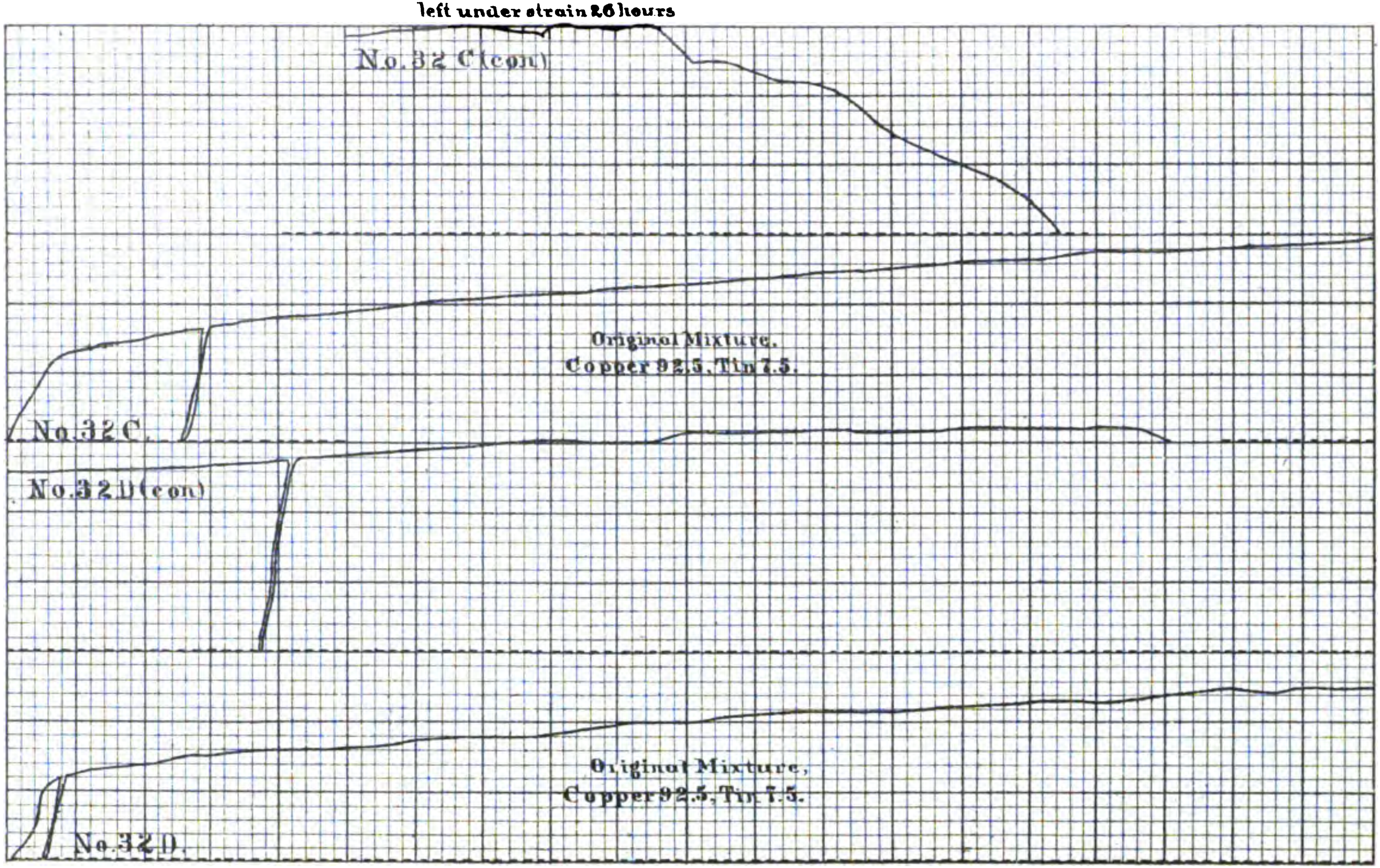
Fac-Simile Autographic Strain Diagrams.



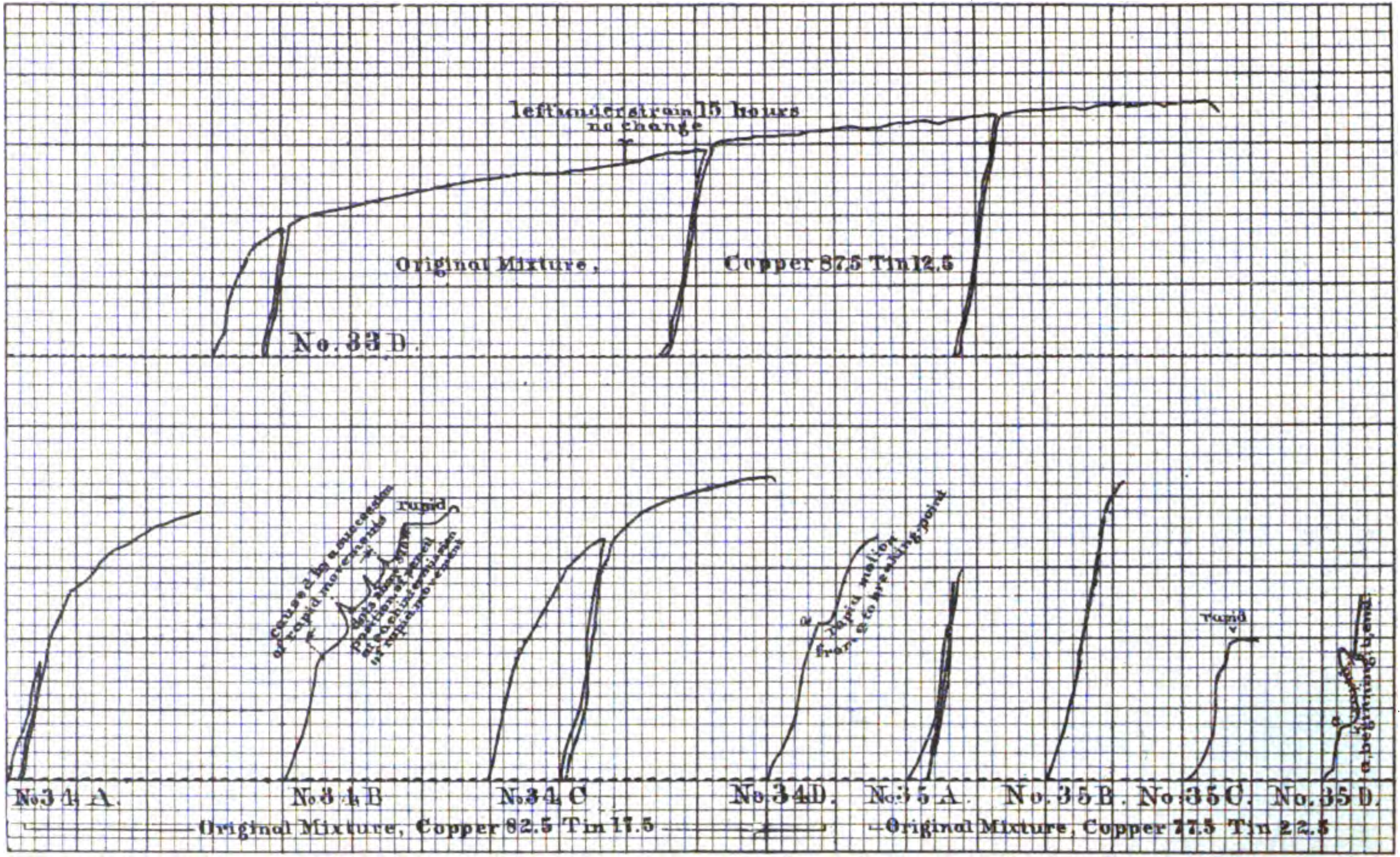

No. 30 C. (con.)
No. 30 C. Cast Copper.
No. 30 C.
No. 30 D (con.)
No. 30 D. Cast Copper.
No. 30 D.


Original Mixture,
Copper 97.5, Tin 2.5.
No. 31 A
Original Mixture,
Copper 97.5, Tin 2.
No. 31 B.
Original Mixture,
Copper 97.5, Tin 2.5.
No. 31 C.
Original Mixture,
Copper 97.5, Tin 2.5.
No. 31 D.
No. 32 A (con)
Left under strain 15 minutes.
Copper 92.5, Tin 2.5.
Original Mixture.
No. 32 A.

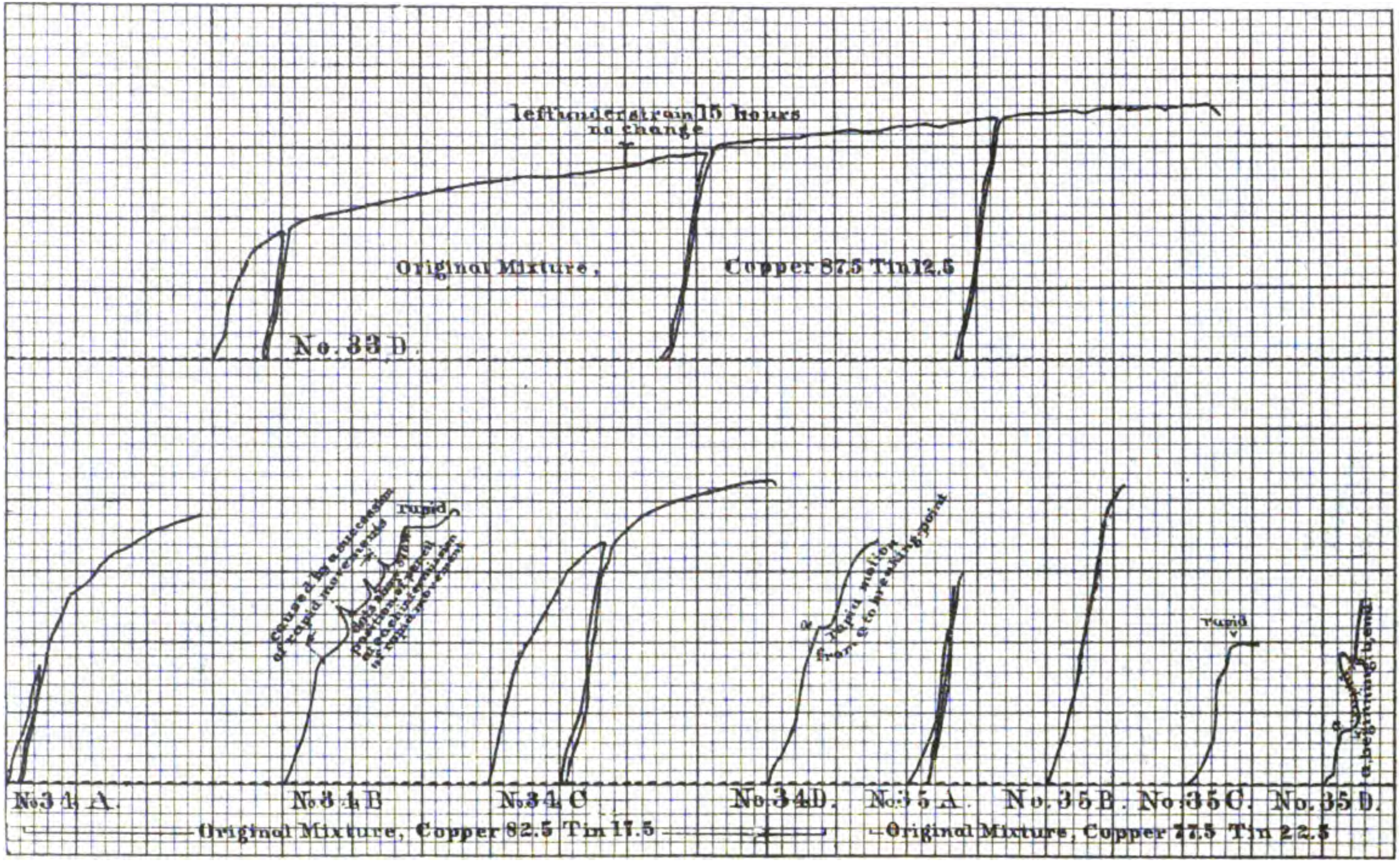

No. 32 B (Iron)
Original Mixture,
Copper 92.5, Tin 7.5.
left under
strain 1 hour
No. 32B

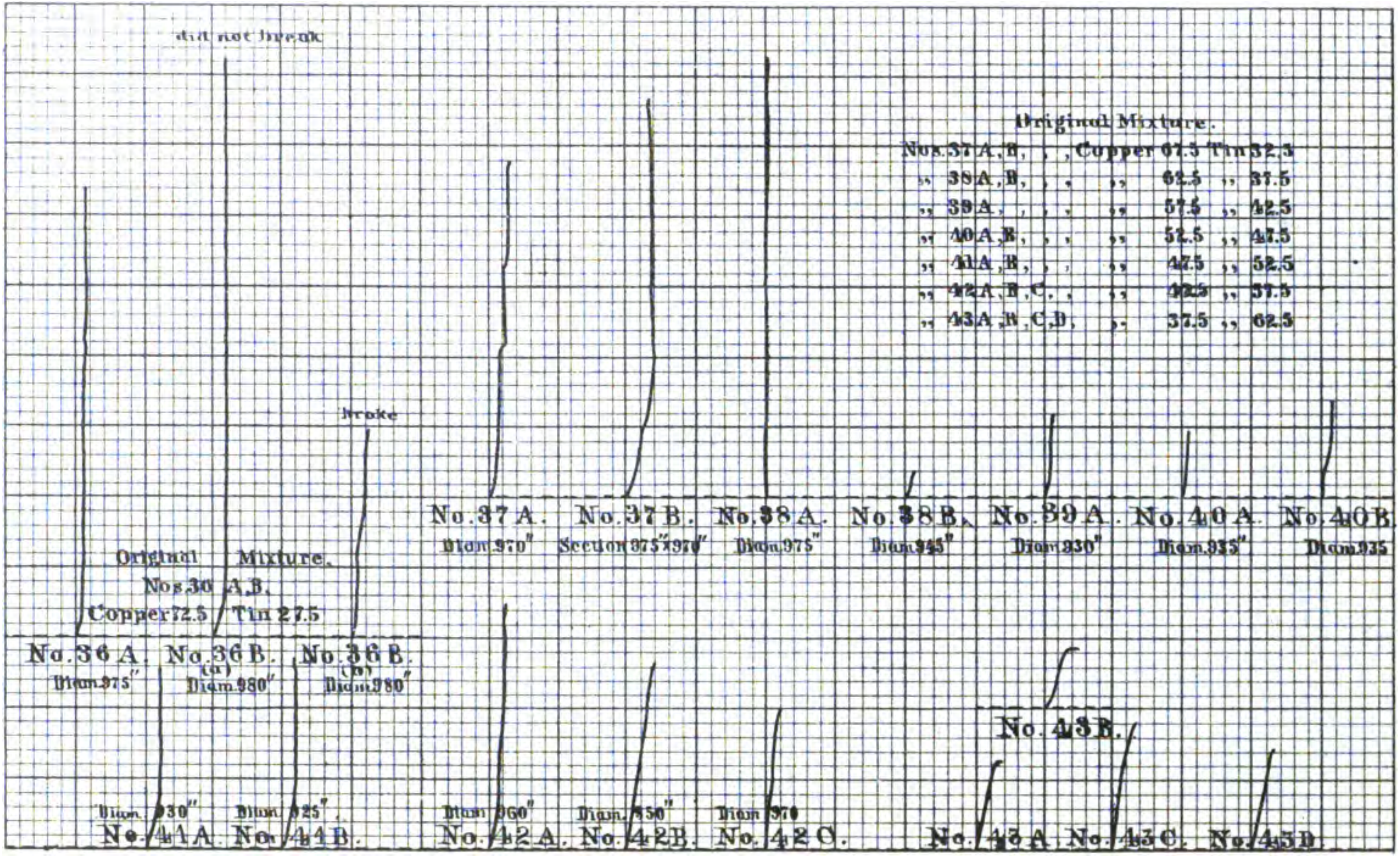

left under strain 26 hours
No. 32 C (con)
Original Mixture,
Copper 92.5, Tin 7.5.
No. 32 C.
No. 32 D (con)
Original Mixture,
Copper 92.5, Tin 7.5.
No. 32 D.

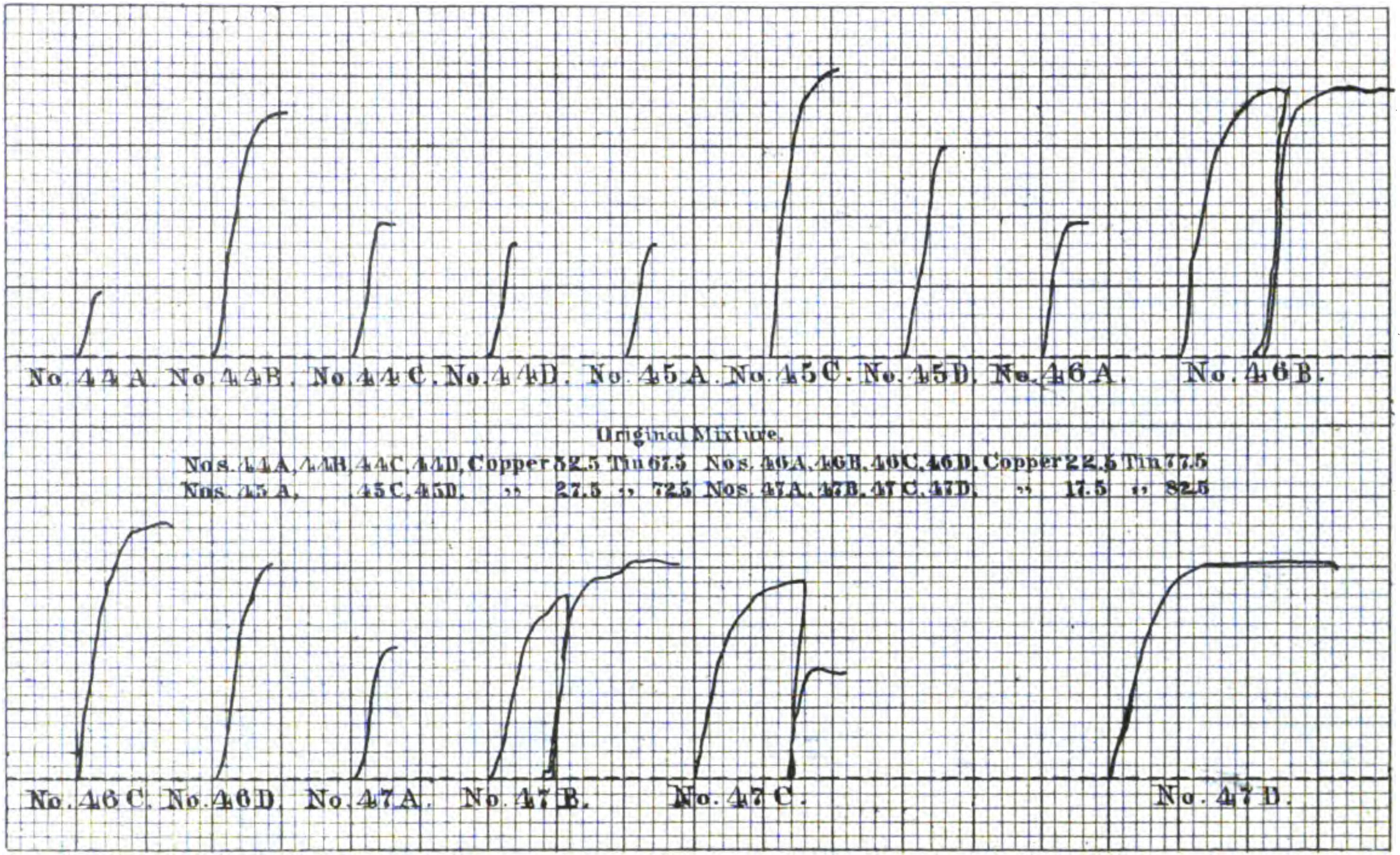
Fac-Simile Autographic Strain Diagrams.



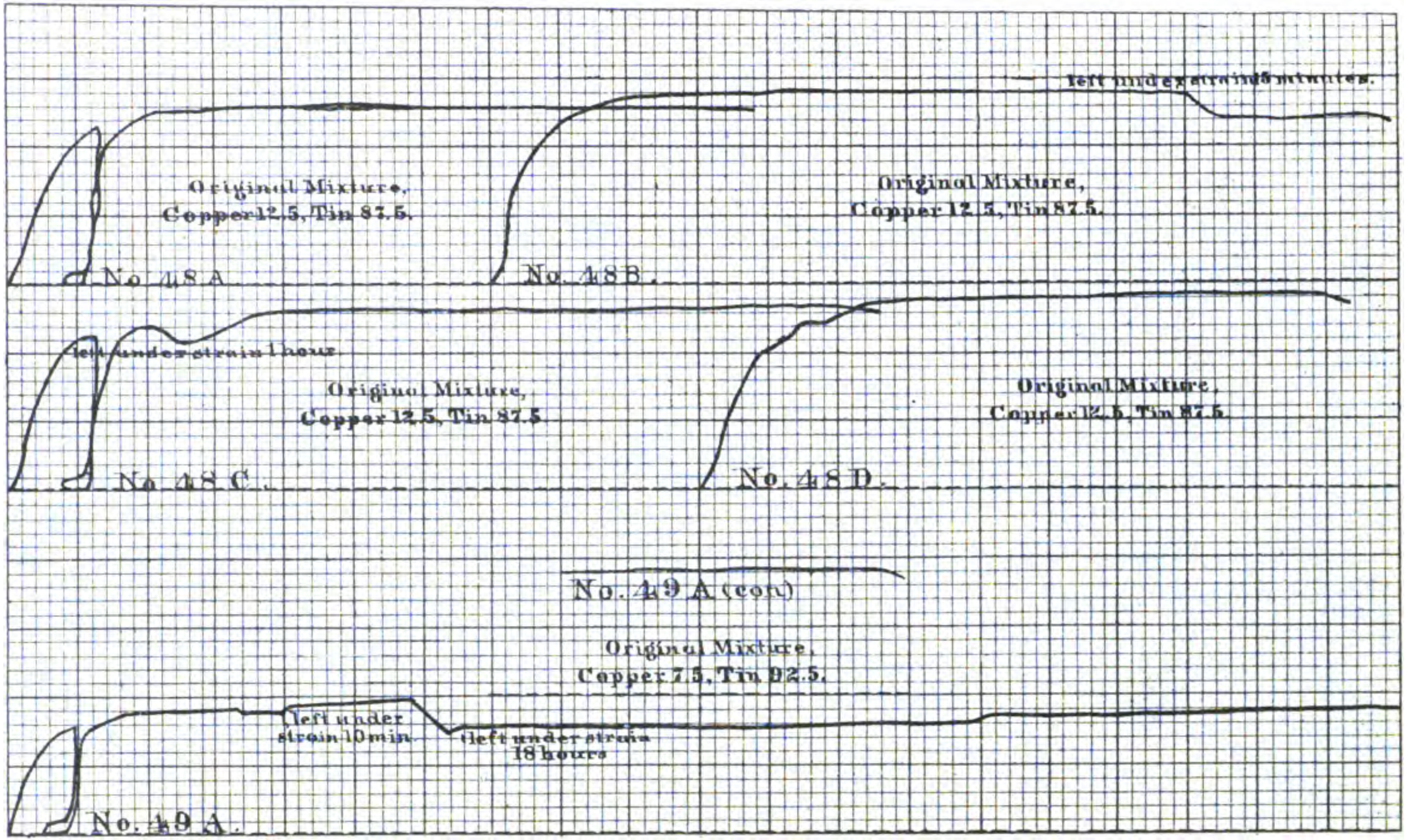
Fac-Simile Autographic Strain Diagrams.

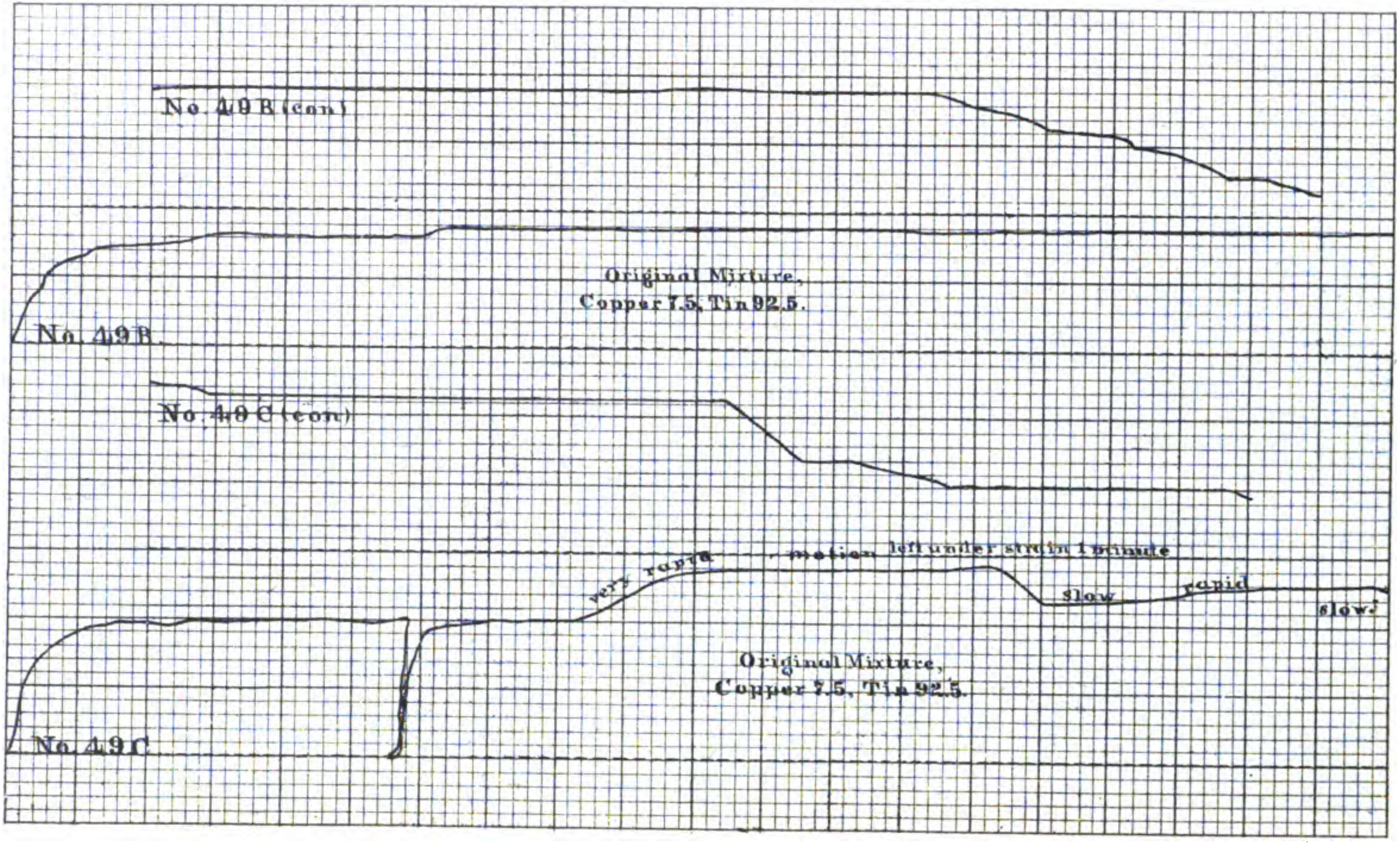


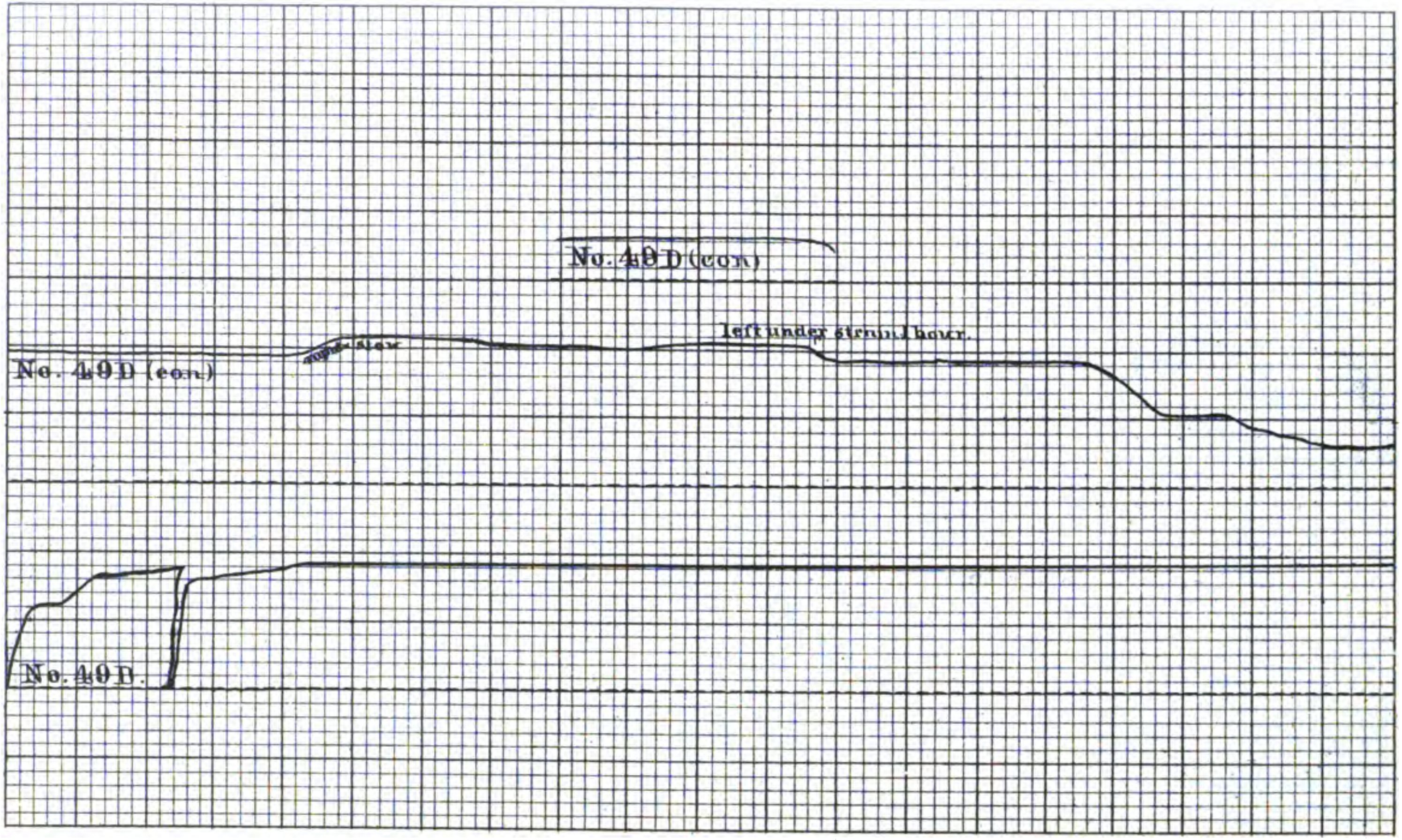

did not break
broke
Original Mixture.
Nos. 37 A, B, , , Copper 67.5 Tin 32.5
,, 38 A, B, , , ,, 62.5 ,, 37.5
,, 39 A, , , ,, 57.5 ,, 42.5
,, 40 A, B, , , ,, 52.5 ,, 47.5
,, 41 A, B, , , ,, 47.5 ,, 52.5
,, 42 A, B, C, , ,, 42.5 ,, 57.5
,, 43 A, B, C, D, ,, 37.5 ,, 62.5
Original Mixture.
Nos. 36 A, B.
Copper 72.5 Tin 27.5
No. 36 A.
Diam. .975"
No. 36 B. (a)
Diam. .980"
No. 36 B. (b)
Diam. .980"
No. 37 A.
Diam. .970"
No. 37 B.
Section .975" × .970"
No. 38 A.
Diam. .975"
No. 38 B.
Diam. .945"
No. 39 A.
Diam. .930"
No. 40 A.
Diam. .935"
No. 40 B.
Diam. .935
No. 41 A.
Diam. .930"
No. 41 B.
Diam. .925"
No. 42 A.
Diam. .960"
No. 42 B.
Diam. .950"
No. 42 C.
Diam. .970
No. 43 A.
No. 43 B.
No. 43 C.
No. 43 D.

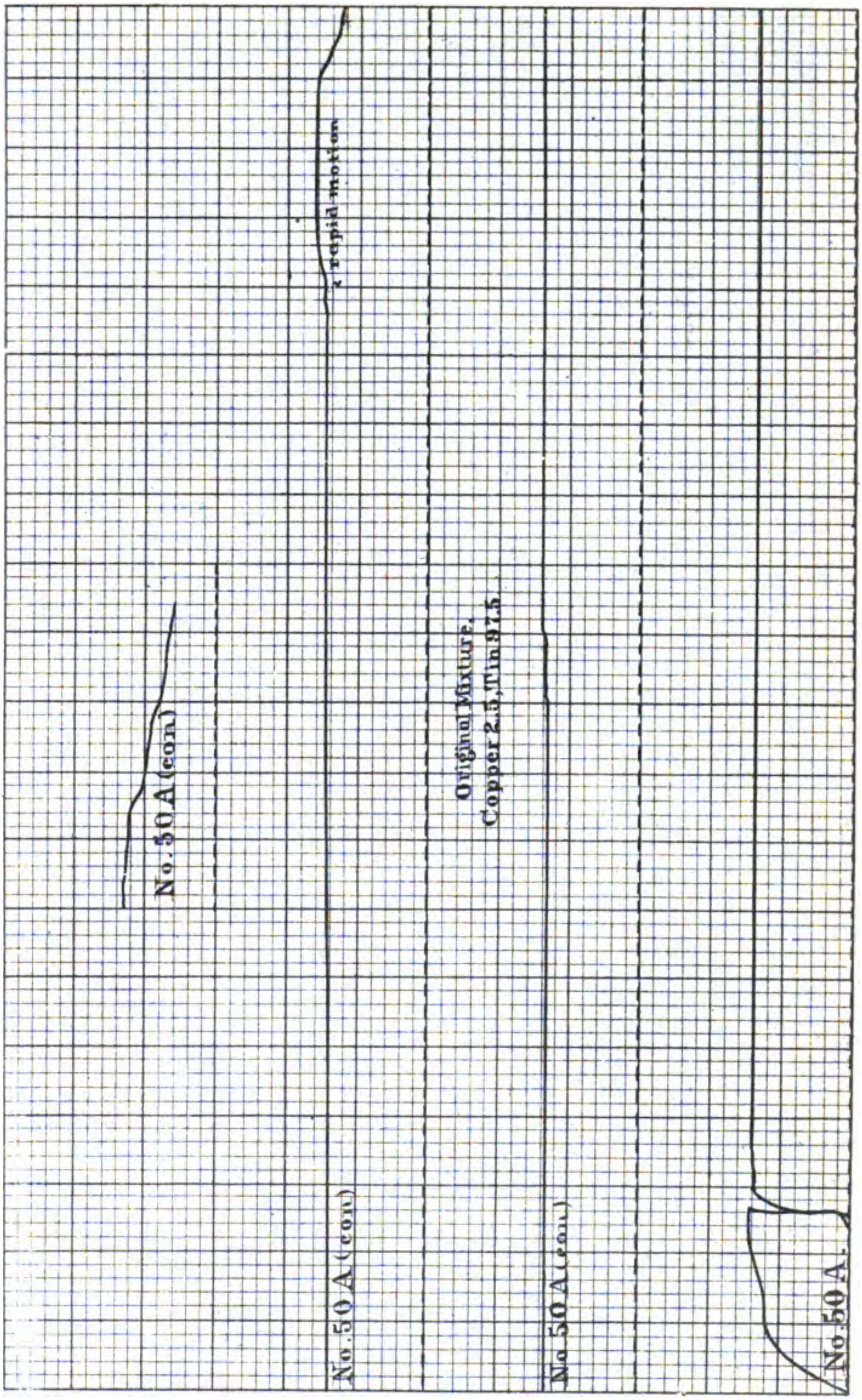

No. 44 A.
No. 44 B.
No. 44 C.
No. 44 D.
No. 45 A.
No. 45 C.
No. 45 D.
No. 46 A.
No. 46 B.
Original Mixture.
Nos. 44A, 44B, 44C, 44D, Copper 32.5 Tin 67.5 Nos. 46A, 46B, 46C, 46D, Copper 22.5 Tin 77.5
Nos. 45 A, 45 C, 45D, " 27.5 " 72.5 Nos. 47A, 47B, 47 C, 47D, " 17.5 " 82.5
No. 46 C.
No. 46 D.
No. 47 A.
No. 47 B.
No. 47 C.
No. 47 D.

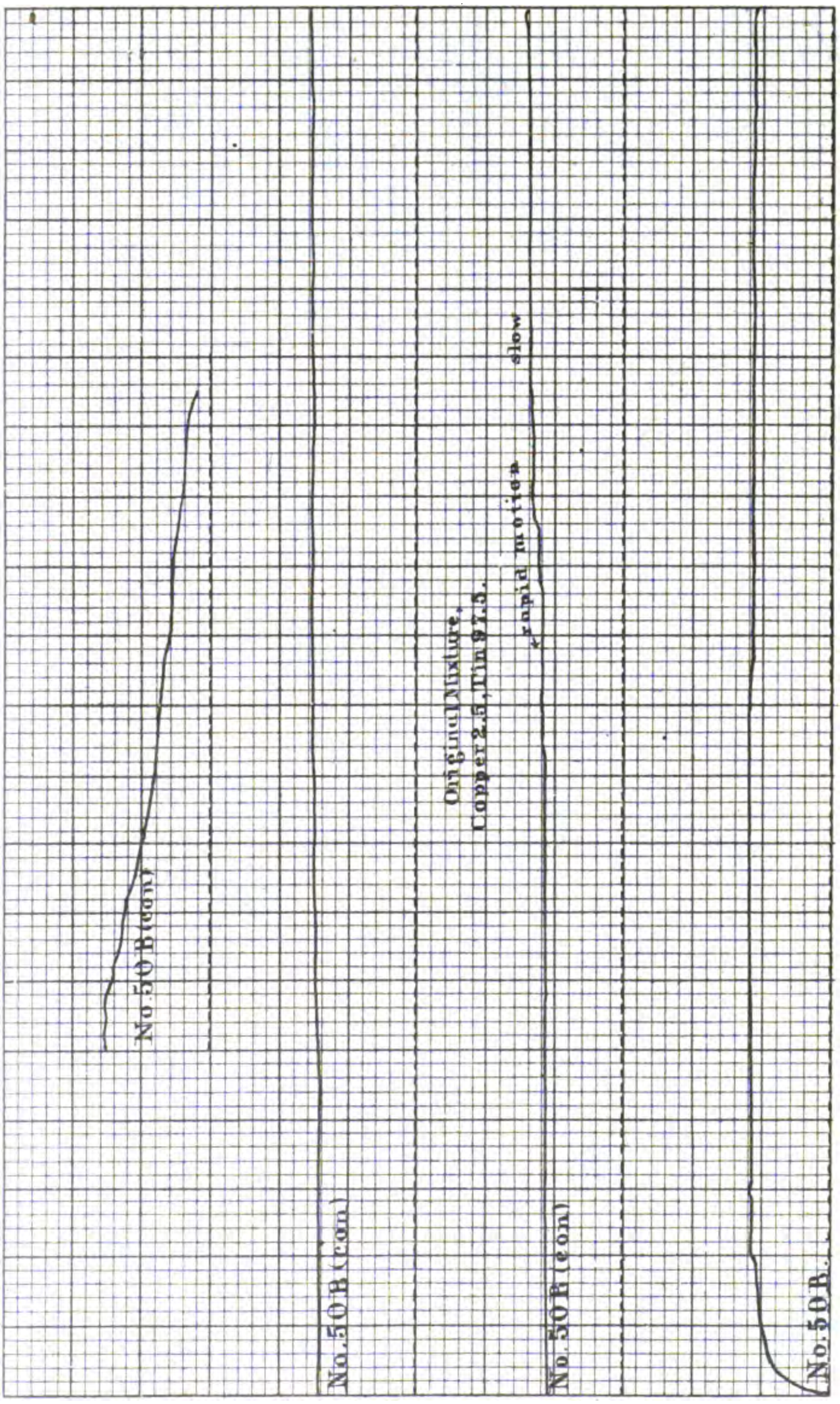
Fac-Simile Autographic Strain Diagrams.

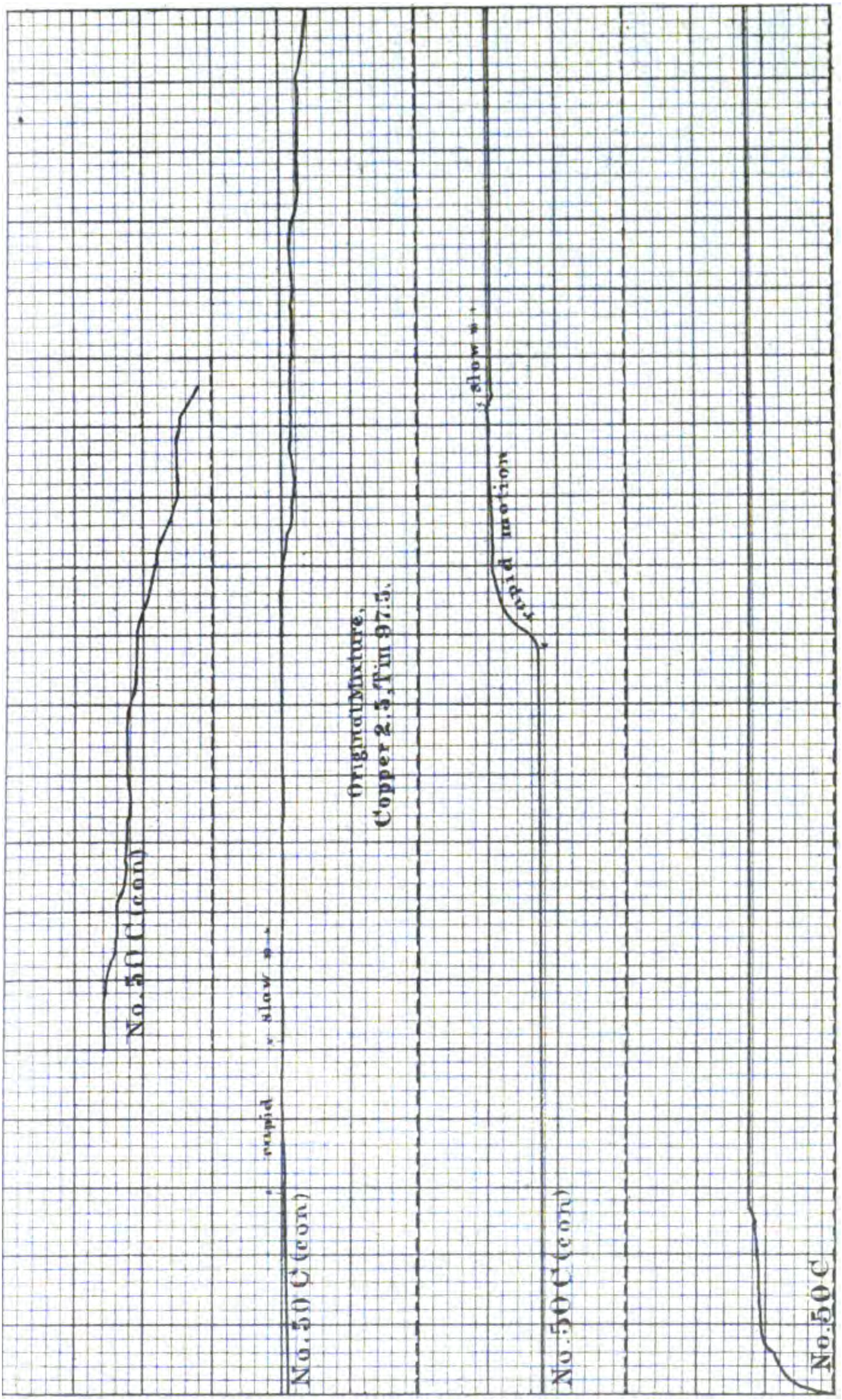



No. 49 B (con)
Original Mixture,
Copper 7.5, Tin 92.5.
No. 49 B
No. 49 C (con)
very rapid
motion
left under strain 1 minute
slow
rapid
slow
Original Mixture,
Copper 7.5, Tin 92.5.
No. 49 C


No. 49 D (con)
left under strain 1 hour.
slow
No. 49 D (con)
No. 49 D.

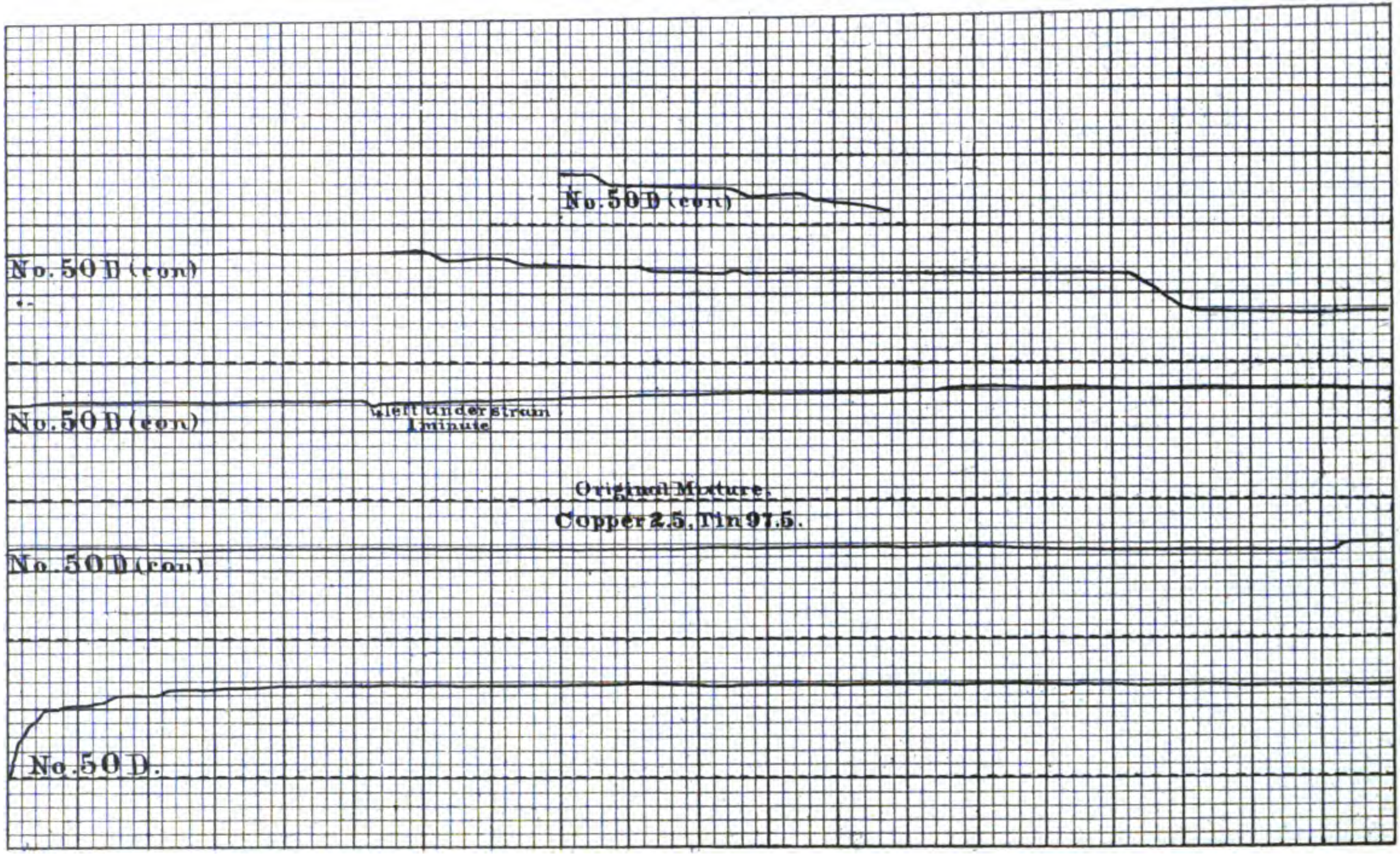

No. 50 A (con)
No. 50 A (con)
rapid motion
Original Mixture,
Copper 2.5, Tin 97.5.
No. 50 A (con)
No. 50 A.

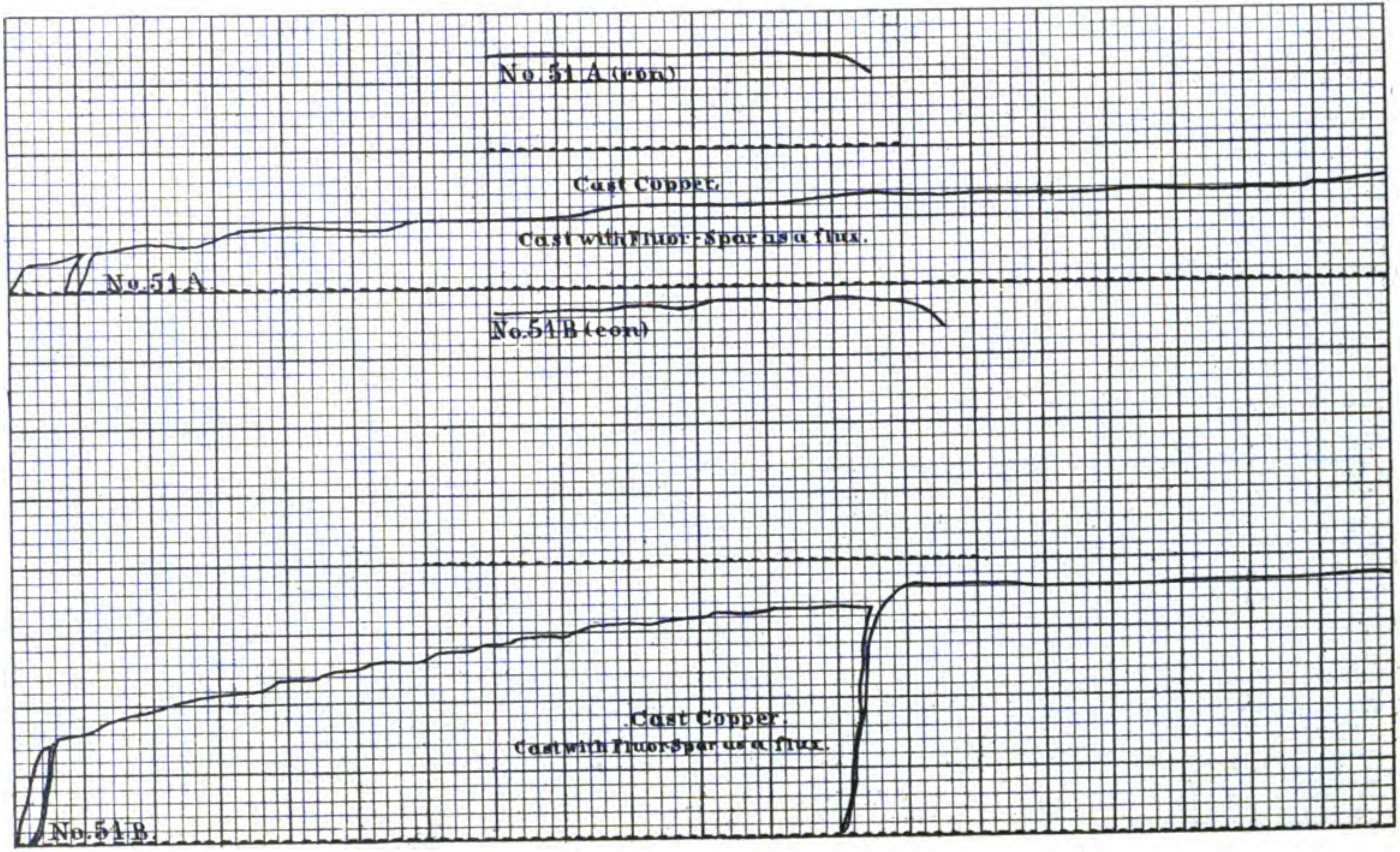

No. 50 B (con)
No. 50 B (con)
Original Mixture,
Copper 2.5, Tin 97.5.
rapid motion
slow
No. 50 B (con)
No. 50 B.

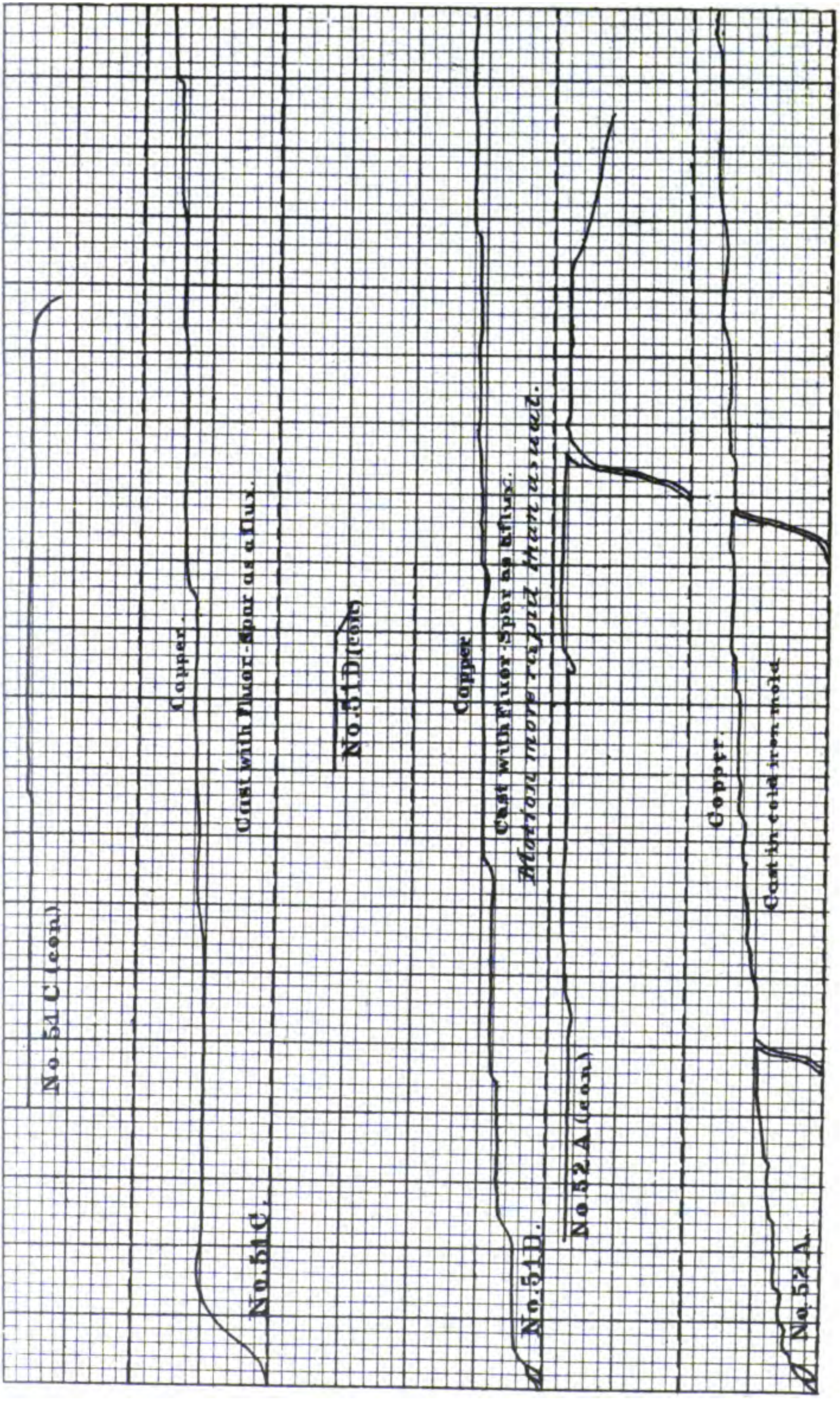


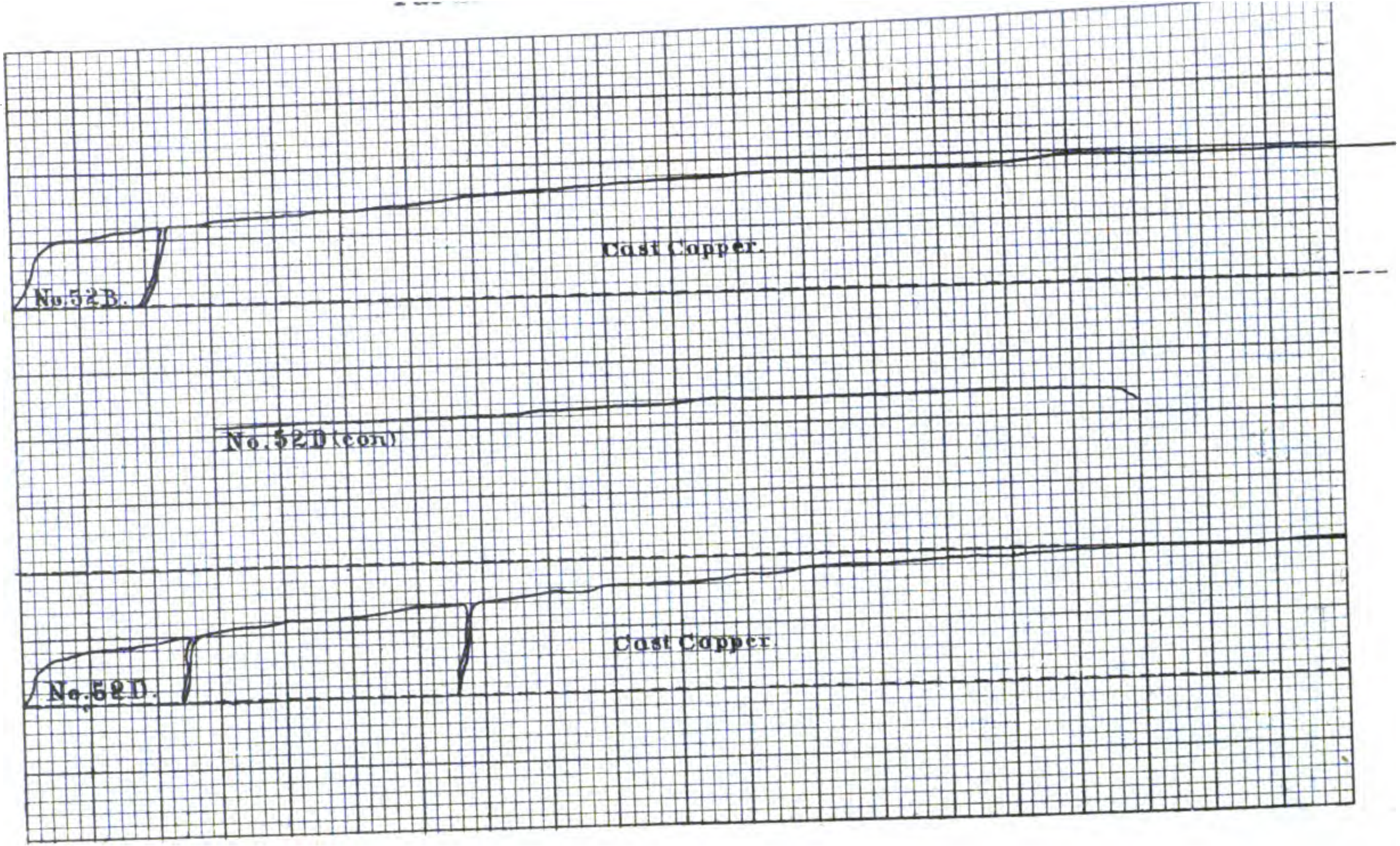
Original Mixture, Copper 2.5, Tin 97.5.

Fac-Simile Autographic Strain Diagram.




No. 51 A (con)
Cast Copper.
Cast with Fluor-Spar as a flux.
No. 51 A.
No. 51 B (con)
Cast Copper.
Cast with Fluor Spar as a flux.
No. 51 B.


No. 51 C (con.)
Copper.
Cast with Fluor-Spar as a flux.
No. 51 C.
No. 51 D (con.)
Copper.
Cast with Fluor-Spar as a flux.
Motion more rapid than usual.
No. 51 D.
No. 52 A (con.)
Copper.
Cast in cold iron mold.
No. 52 A.


Cast Copper.
No.52B.
No. 52D (con)
Cast Copper
No.52D.

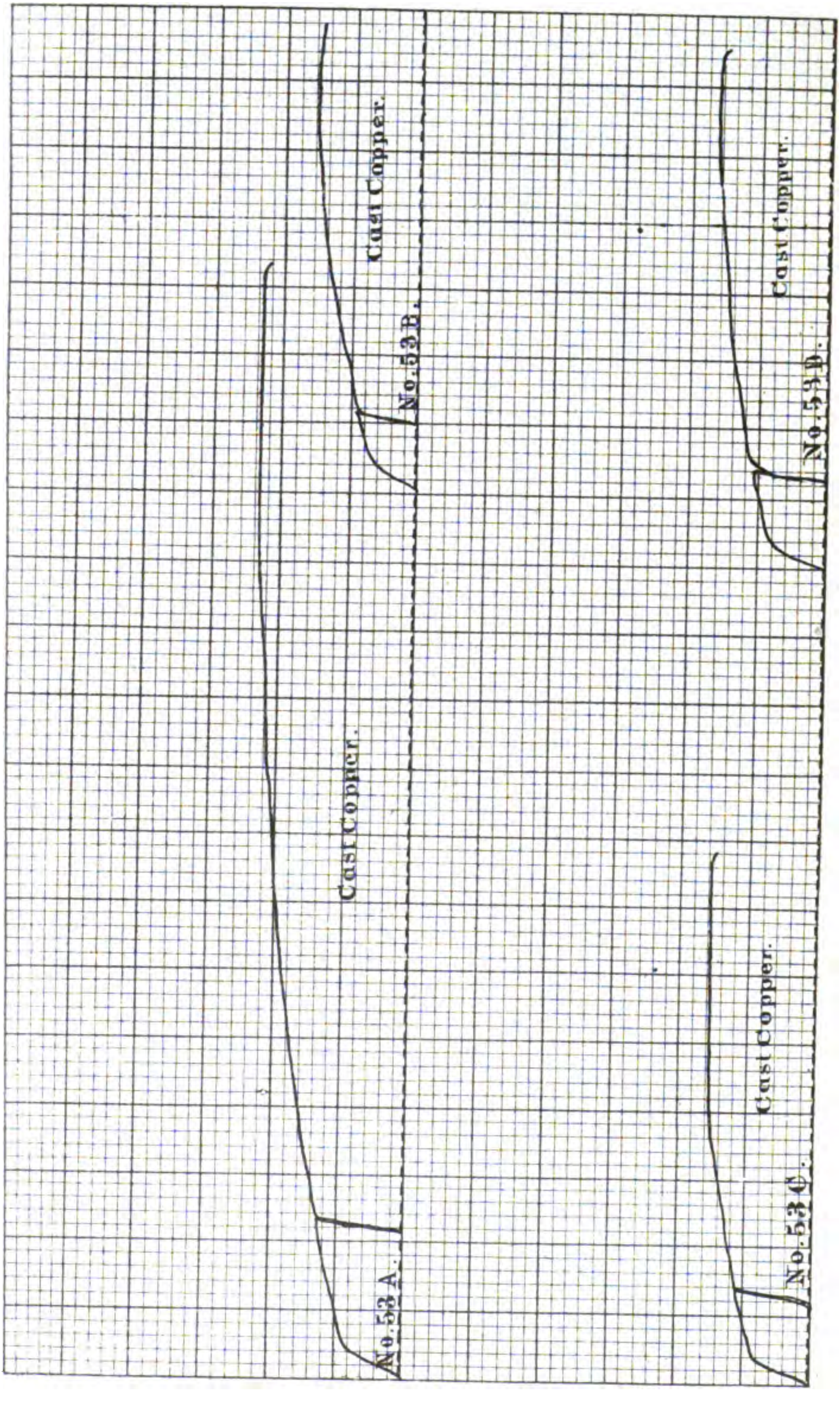

No.53 B.
Cast Copper.
No.53 A.
Cast Copper.
No.53 D.
Cast Copper.
No.53 C.
Cast Copper.

PLATE LXXII.

Fac-Simile Autographic Strain Diagrams.

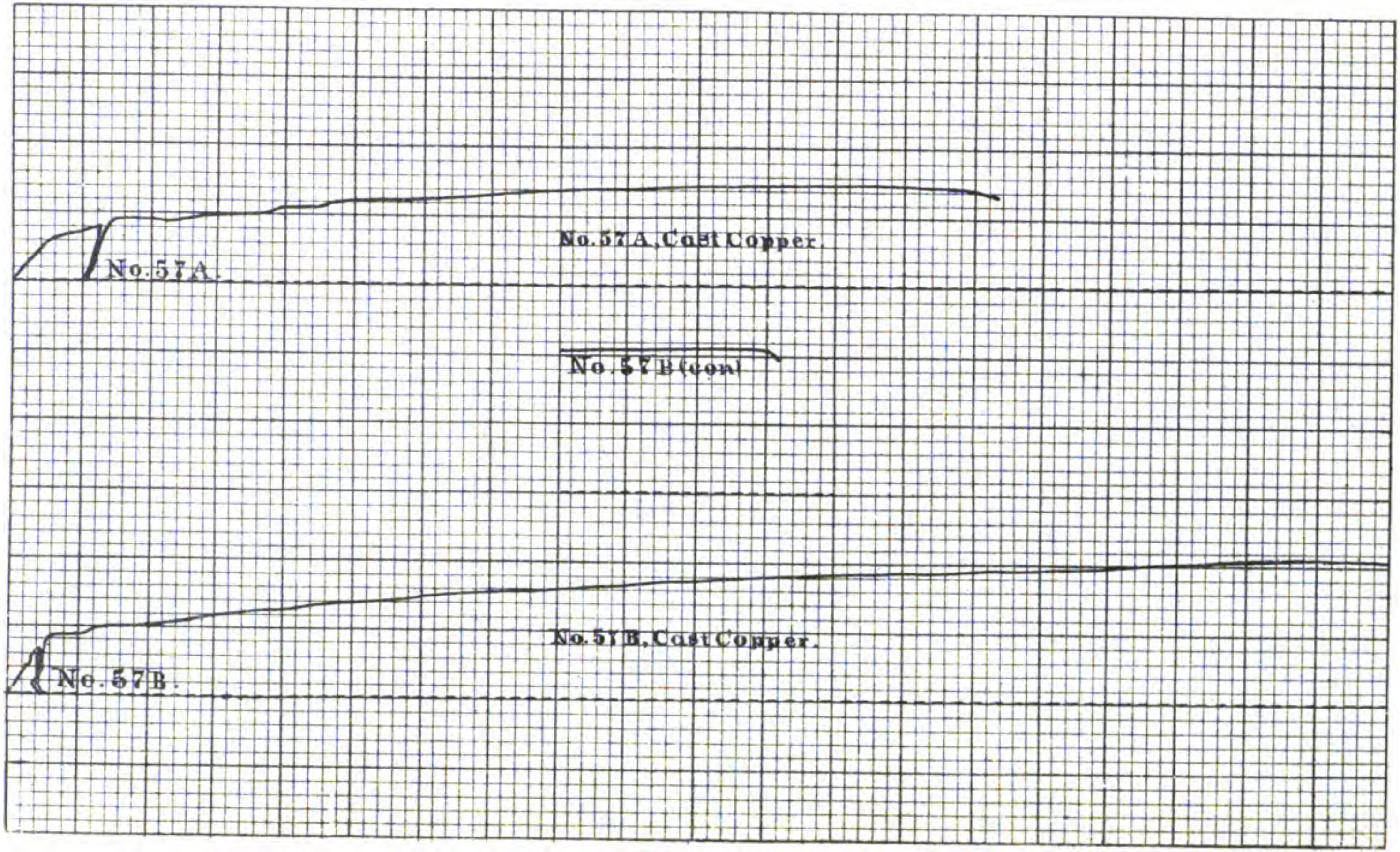
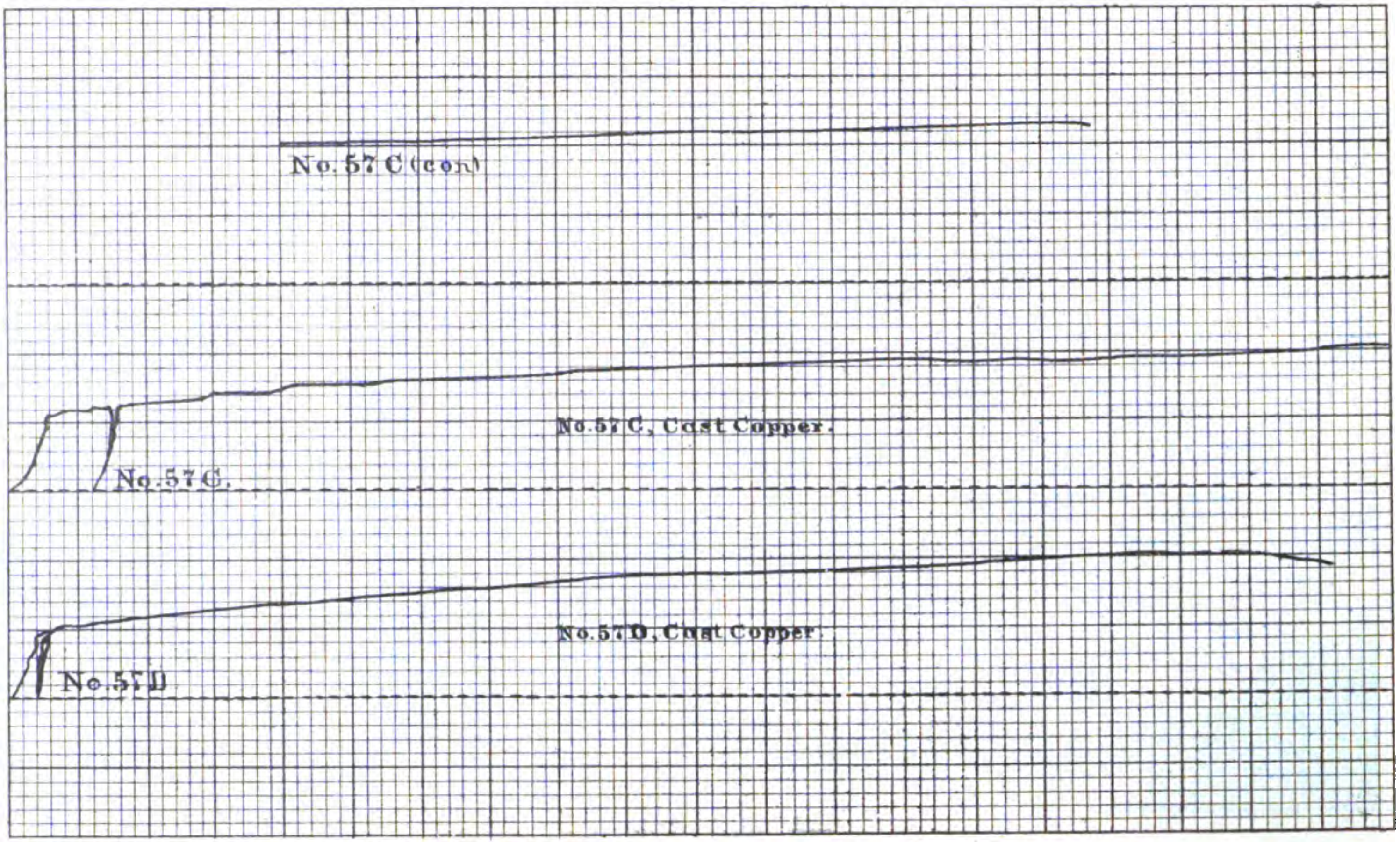
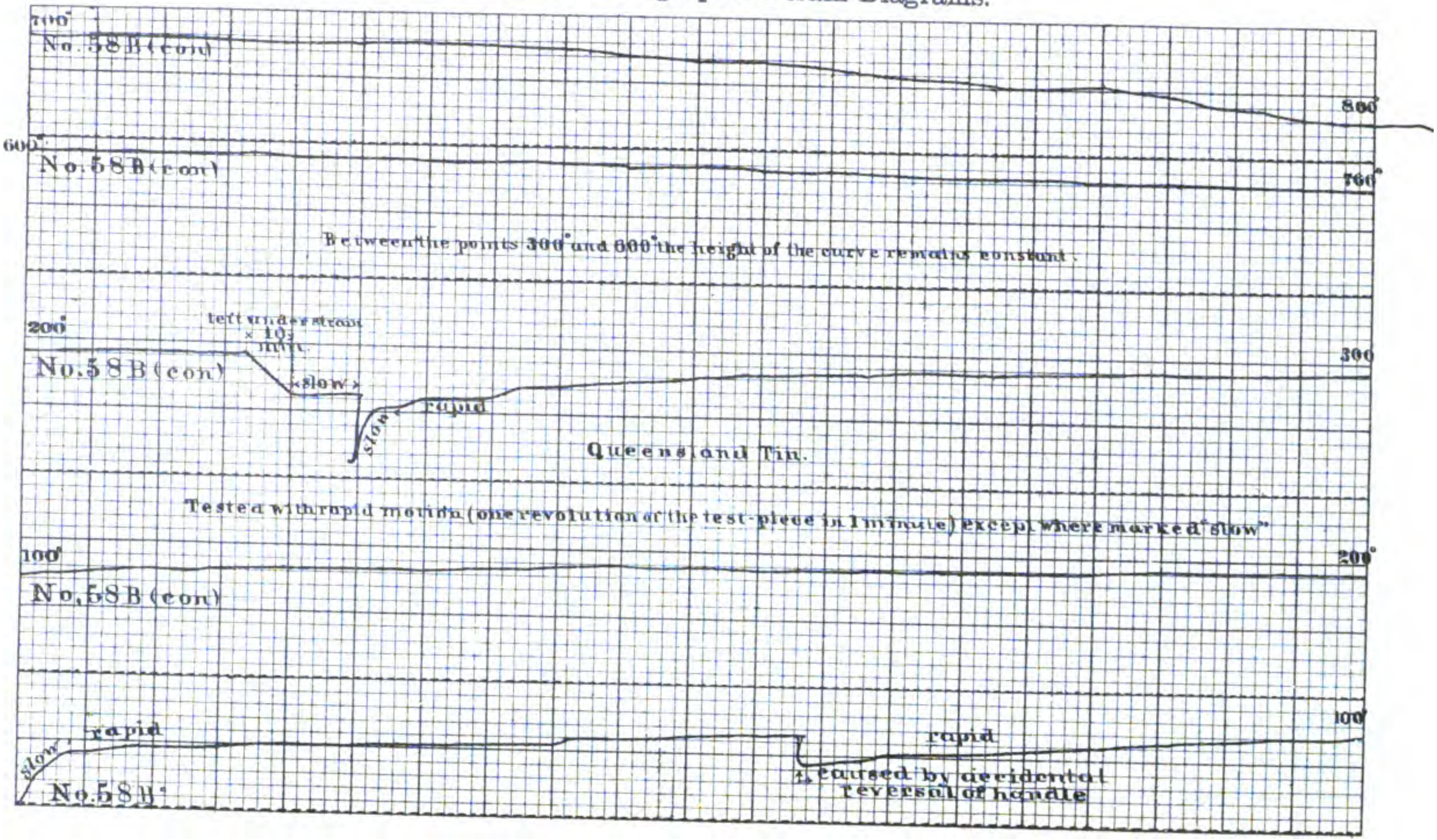


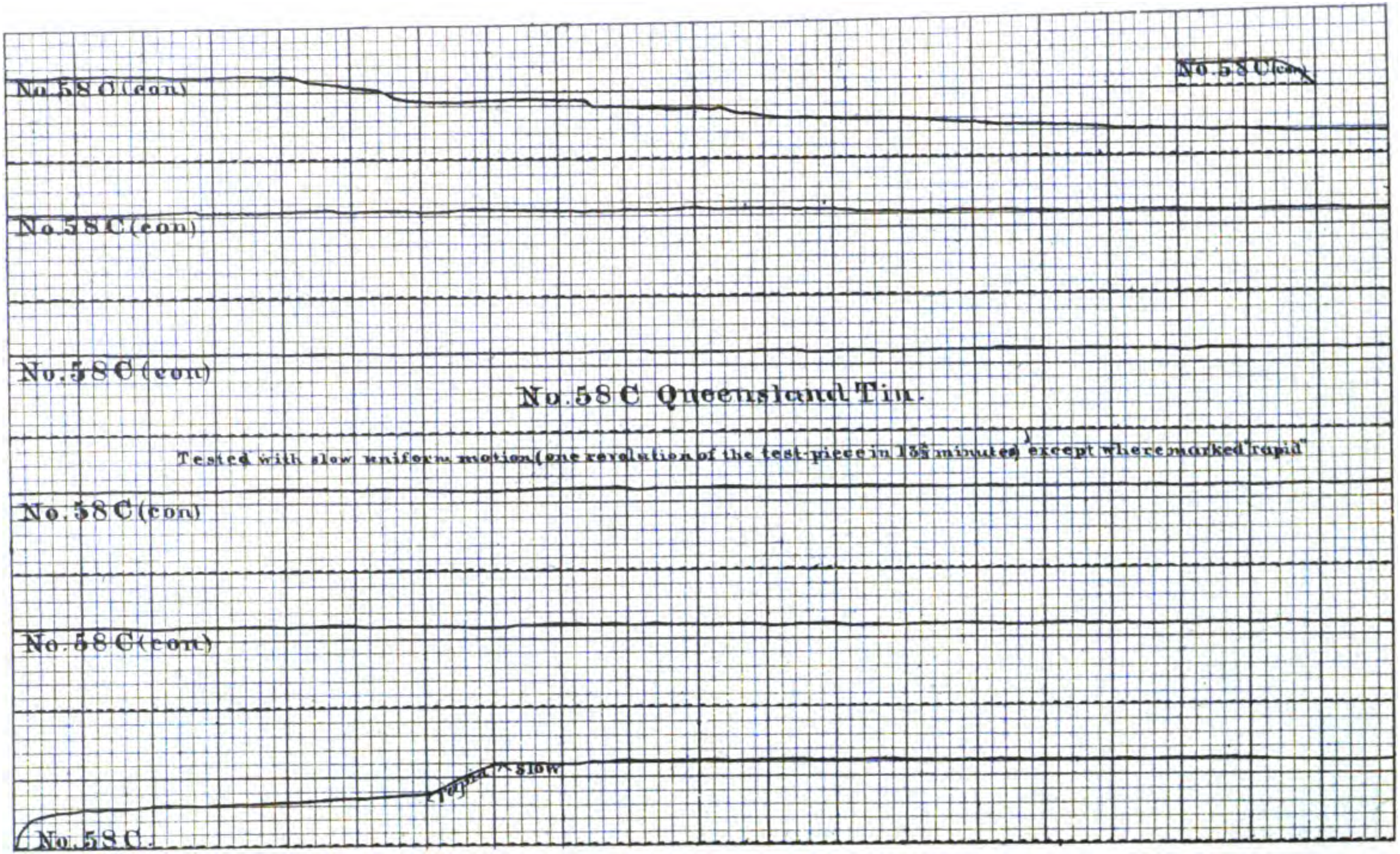
PLATE LXXIII.

Fac-Simile Autographic Strain Diagrams.



Fac-Simile Autographic Strain Diagrams.

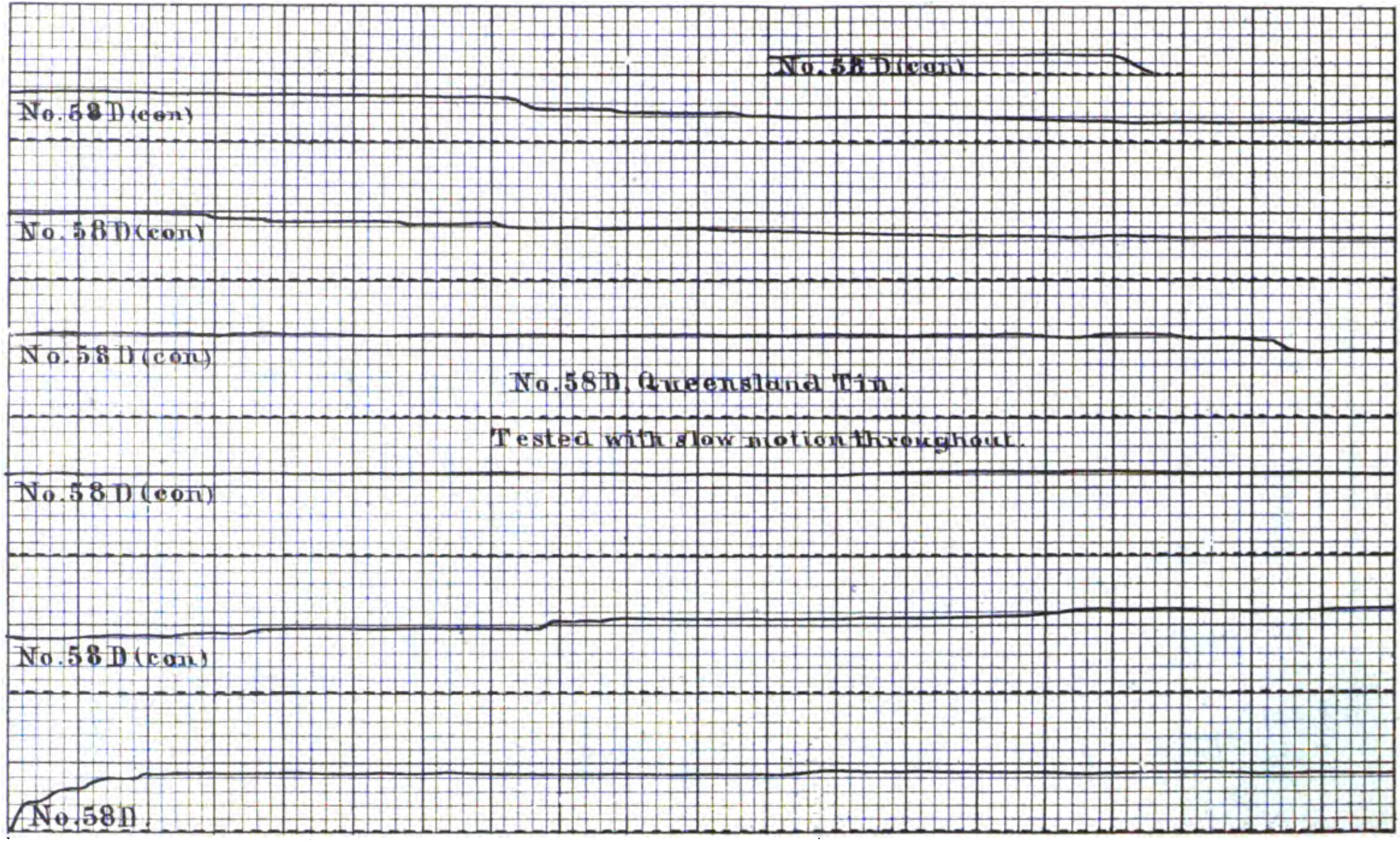




No. 58 C Queensland Tin.

Tested with slow uniform motion (one revolution of the test-piece in $13\frac{2}{3}$ minutes) except where marked "rapid"

Fac-Simile Autographic Strain Diagrams.



KEY TO PLATES OF FAC-SIMILE AUTOGRAPHIC STRAIN-DIAGRAMS.

Number of diagram.	Number of plate.	Diameter of specimen.	Vertical scale of torsional moments.		Equivalent scale for a standard specimen, 1" long x .625" diam.	
			Foot-pounds per inch of ordinate.	Constant for friction.	Foot-pounds per inch of ordinate.	Constant for friction.
		Inches.				
1 A	XXII	0.625	117.44295	10.8555		
C	do	"	"	"		
D	do	"	"	"		
2 A	do	"	"	"		
B	XXIII	"	"	"		
C	XXIV	"	"	"		
D	do	"	"	"		
3 A	XXV	"	"	"		
B	XXVIII	"	"	"		
C	XXVI	"	"	"		
D	XXVII	"	"	"		
4 A	XXVIII	"	"	"		
B	XXIX	"	"	"		
C	do	"	"	"		
D	do	"	"	"		
A	XXX	"	"	"		
B	do	"	"	"		
C	do	"	"	"		
D	do	"	"	"		
6 A	XXXI	"	"	"		
B	do	"	"	"		
C	do	"	"	"		
D	do	"	"	"		
7 A	XXXII	"	"	"		
B	do	"	"	"		
C	do	"	"	"		
D	do	"	"	"		
8 A	do	"	"	"		
B	do	"	"	"		
C	do	"	"	"		
D	do	"	"	"		
9 D	do	0.970	42.152	1.672	11.276	0.447
11 A	do	0.955	17.011	0.675	4.768	0.189
12 A	do	0.900	"	"	5.697	0.226
13 C	do	0.960	"	"	4.693	0.186
14 D	do	0.955	"	"	4.768	0.189
15 B	XXXIII	0.960	"	"	4.693	0.186
C	do	1" x 1"□	"	"		
D	do	0.940	"	"	5.000	0.198
16 A	do	0.945	42.152	1.672	12.196	0.484
B*a*	do	0.945	17.011	0.675	12.196	0.484
B*b*	do		42.152	1.672		
C	do	0.890	17.011	0.675	5.886	0.234
17 A	XXXIV	0.940	42.152	1.672	12.389	0.491
C	do	0.922	"	"	13.194	0.523
18 A	do	0.895	"	"	14.353	0.569
C	do	0.625	20.18	3.156		
D	do	"	"	"		
19 A	do	"	"	"		
B	do	"	"	"		
D	do	"	"	"		
20 A	do	"	"	"		
B	do	"	"	"		
C	do	"	"	"		
D	do	"	"	"		
21 A	do	"	"	"		
22 A	do	"	"	"		
B	do	"	"	"		
C	do	"	"	"		
D	do	"	"	"		
23 A	XXXV	"	"	"		
C	do	"	"	"		
D	do	"	"	"		
24 A	do	"	"	"		
B	do	"	"	"		
C	XXXVI	"	"	"		
D	do	"	"	"		
25 A	XXXVII	"	"	"		
B	do	"	"	"		

KEY TO PLATES OF FAC-SIMILE AUTOGRAPHIC STRAIN-DIAGRAMS—Continued.

Number of diagram.	Number of plate.	Diameter of specimen.	Vertical scale of torsional moments.		Equivalent scale for a standard specimen, 1″ long x .625″ diam.	
			Foot-pounds per inch of ordinate.	Constant for friction.	Foot-pounds per inch of ordinate.	Constant for friction.
		Inches.				
C	XXXVIII	0.625	0.625	20.18	....	....
D	....do	“	“	“	....	....
26 A	XXXIX	“	“	“	....	....
B	... do	“	“	“	....	....
C	XL	“	“	“	....	....
D	....do	“	“	“	....	....
27 A	XLI	“	“	“	....	....
B	....do	“	“	“	....	....
C	XLII	“	“	“	....	....
D	XLIII	“	“	“	....	....
28 A	XLIV	“	117.44295	10 855	....	....
B	XLV	“	20.18	8.156	....	....
C	XLVI	“	“	“	....	....
D	XLVII	“	“	“	....	....
29 A	XLVIII	“	“	“	....	....
B	XLIX	“	“	“	....	....
C	L	“	“	“	....	....
D	LI	“	“	“	....	....
30 A	LII	“	100.81	4	....	....
B	....do	“	“	“	....	....
C	LIII	“	“	“	....	....
D	... do	“	“	“	....	....
31 A	LIV	“	“	“	....	....
B	... do	“	“	“	....	....
C	... do	“	“	“	....	....
D	....do	“	“	“	....	....
32 A	... do	“	“	“	....	....
B	LV	“	“	“	....	....
C	LVI	“	100.547	5	....	....
D	....do	“	100.81	4	....	....
33 A	LVII	“	“	“	....	....
B	....do	“	100.547″	5	....	....
C	....do	“	100.81	4	....	....
D	LVIII	“	“	“	....	....
34 A	....do	“	“	“	....	....
B	.... do	“	“	“	....	....
C	....do	“	“	“	....	....
D	....do	“	“	“	....	....
35 A	....do	“	“	“	....	....
B	....do	“	“	“	....	....
C	....do	“	“	“	....	....
D	... do	“	“	“	....	....
36 A	LIX	0.975	42.152	1.672	11.103	0.4404
B	....do	0.980	100.81	4	26.150	1.0376
37 A	....do	0.970	42.152	1.672	11.276	0.447
B	....do	.975″ x .970″	“	“	....	....
38 A	....do	0.975	“	“	11.103	0.4404
B	....do	0.945	“	“	12.196	0.484
39 A	....do	9.930	“	“	12.793	0.5074
40 A	... do	0.935	“	“	12.591	0.5
B	....do	0.935	“	“	12.591	0.5
41 A	....do	0.930	“	“	12.793	0.5074
B	....do	0.925	“	“	13.004	0.516
42 A	....do	0.960	“	“	11.630	0.461
B	....do	0.950	“	“	12.005	0.476
C	....do	0.970	“	“	11.276	0.447
43 A	....do	0.625	17.06	1.146	....	....
B	....do	“	“	“	....	....
C	....do	“	“	“	....	....
D	....do	“	“	“	....	....
44 A	LX	“	“	“	....	....
B	....do	“	“	“	....	....
C	....do	“	“	“	....	....
D	....do	“	“	“	....	....
45 A	....do	“	“	“	....	....
C	....do	“	“	“	....	....
D	....do	“	“	“	....	....
46 A	....do	“	“	“	....	....
B	....do	“	“	“	....	....

KEY TO PLATES OF FAC-SIMILE AUTOGRAPHIC STRAIN-DIAGRAMS—Continued.

Number of diagram.	Number of plate.	Diameter of specimen.	Vertical scale of torsional moments.		Equivalent scale for a standard specimen, 1" long x .625" diam.	
			Foot-pounds per inch of ordinate.	Constant for friction.	Foot-pounds per inch of ordinate.	Constant for friction.
		Inches.				
C	LX	0.625	17.06	1.146	....	....
D	....do	"	"	"	....	....
47 A	....do	"	"	"	....	....
B	....do	"	"	"	....	....
C	....do	"	"	"	....	....
D	....do	"	"	"	....	....
48 A	LXI	"	"	"	....	....
B	....do	"	"	"	....	....
C	....do	"	"	"	....	....
D	....do	"	"	"	....	....
49 A	....do	"	"	"	....	....
B	LXII	"	"	"	....	....
C	....do	"	"	"	....	....
D	LXIII	"	"	"	....	....
50 A	LXIV	"	"	"	....	....
B	LXV	"	"	"	....	....
C	LXVI	"	"	"	....	....
D	LXVII	"	"	"	....	....
51 A	LXVIII	"	117.44295	10.855	....	....
B	....do	"	67.86	5.442	....	....
C	LXIX	"	117.44295	10.855	....	....
D	....do	"	"	"	....	....
52 A	....do	"	"	"	....	....
B	LXX	"	100.81	4	....	....
D	... do	"	"	"	....	....
53 A	LXXI	"	"	"	....	....
B	....do	"	"	"	....	....
C	....do	"	"	"	....	....
D	....do	"	"	"	....	....
57 A	LXXII	"	"	"	....	....
B	....do	"	"	"	....	....
C	LXXIII	"	"	"	....	....
D	....do	"	"	"	....	....
58 B	LXXIV	"	17.011	0.675	....	....
C	LXXV	"	"	"	....	....
D	LXXVI	"	"	"	....	....

APPENDIX.

SELECTED PAPERS ON THE METALLIC ALLOYS.

SELECTED PAPERS ON THE METALLIC ALLOYS.

AMERICAN SOCIETY OF CIVIL ENGINEERS.

[Incorporated 1852.]

NOTE ON THE RESISTANCE OF MATERIALS.

A paper by Prof. Robert H. Thurston, Member of the Society. Read November 17, 1875.

November 19, 1873, I had the pleasure of presenting to the society a note (subsequently published in "Transactions"*) in which I made known the discovery of an increased power of resisting stress which was developed in iron and steel, by their subjection to a strain which produced distortion beyond the elastic limit and gave them a set. This was more fully considered in a paper read April 4, 1874,† and the phenomenon more thoroughly examined in its bearings upon the practical work of the engineer, and the experimental researches by which its nature had been revealed were described. Subsequently Commander L. A. Beardslee, U. S. N., discovered the same principle independently and by a different method of experiment, and since the republication of these facts in foreign periodicals, experimenters in Europe have announced the observation of similar phenomena under identical or similar conditions.

The writer, since the announcement of this important peculiarity in the behavior of metals, has made a very large number of experiments upon irons, steels, and on various alloys, as well as other simple metals, and upon many qualities of each. The Mechanical Laboratory of the Stevens Institute of Technology has been called upon to test large numbers of specimens of commercial qualities of nearly every kind of metal used as a material of construction, and these often furnished opportunities to pursue the investigation. The special work now in progress under the direction of the United States board recently appointed to test iron, steel, and other metals, has been particulary useful in permitting the examination of the behavior of the copper-tin alloys.

The results of observation, so far as the experience of the writer has now extended, may be briefly summarized as follows:

In iron, an elevation of the elastic limit very generally occurs under stress, to a marked degree. It is very variable in maximum amount, and in the time required to produce it. Some metals exhibit it to an almost imperceptible extent after long exposure to strain; other irons experience a great increase in their power of resistance to stress within the new elastic limit, and its development may sometimes be the result of but a very brief period of exposure to the action of that molecular rearrangement which seems to be the cause of this phenomenon. The maximum increase noted by the writer is about 30 per cent., and the time required for its development has sometimes not exceeded a half minute; in other cases, the elevation of the elastic limit has been scarcely perceptible after several days.

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* LXI. Note on the Resistance of Materials; R. H. Thurston. Vol. II, page 239.

† LXXXII. On the Mechanical Properties of Materials of Construction; R. H. Thurston. Vol. III, page 1.

In steel, the same variation in the amount and in the time needed for its development has been noticed.

In the various other metals and in the alloys, this action has not been found to occur in any case where the material was inelastic; on the contrary, it has been found that inelastic metals—particularly tin and metallic alloys of similar mechanical properties—have, when exposed to constant stresses exceeding their so-called elastic limits, gradually and continuously yielded by a process of flow which, in some instances, was observed to proceed uninterruptedly for days together, and would apparently have continued until fracture ensued, could the experiment have been carried to that extent.

These experiments have ledthe writer to suppose, as intimated in the paper referred to, that the force of cohesion and that force which gives stability of form to solids and distinguishes them from liquids—a force called by Professor Henry "polarity"—are quite distinct modes of molecular action. Some materials, as the stronger of the ductile metals, exhibit great cohesion, and yet may flow under the action of a constant force, as in the cases last referred to above; while others—for example, over-hardened steel—may have great polarity, and consequently great stability of form, while exhibiting a relatively low power of cohesion.

It is in metals which belong to the latter class, rather than in those of the former character, that the elevation of the elastic limit by strain is observed. The explanation already proposed, that this apparent increase of resisting power is really a consequence of the relief of internal stresses due to methods of manufacture, or to circumstances which have, by external application of force, prevented such a molecular arrangement of particles as would naturally take place, still seems to the writer the most satisfactory explanation. The close relation of this action to that observed by Professor Johnson thirty years ago, and illustrated by the process termed by him "thermo-tension," has been pointed out on a former occasion.

During the two years which have elapsed since the first announcement of the phenomenon of the elevation of the elastic limit by strain, a large mass of valuable data has been accumulated, which may at some future time be collated. In no case, in the whole range of these researches, has any indication been observed of a reduction of resisting power during the distortion of metal between—on the one hand—the passing of the elastic limit, and—on the other hand—the point at which incipient rupture commences.

CONCLUSIONS.—The writer is therefore led to conclude that the simple extension or straining of any member of any metallic structure is not a cause of weakness, except where it produces an actual reduction of section resisting rupture, or where it brings the line of stress into a new direction, in which it acts either with a larger component of force in the former direction of stress, or, as in the case of a reflexure of the metal, it takes the material at disadvantage strategetically, after a new disposition of its particles has taken place.

The conclusion seems also proper, that the elevation of the elastic limit by strain can only occur in metals which are elastic, and are capable of being placed in a condition of reduced resisting power by internal stress by artificial or external force.

Finally, the conclusion has been arrived at, that structures are not weakened by stresses exceeding the elastic resisting power of their members, whatever the material of which they are composed; and even when made of metals having no elasticity and capable of yielding, like tin, by flow, unless such strains as are produced are productive of actual molecular disruption.

AMERICAN SOCIETY OF CIVIL ENGINEERS.

[Incorporated 1852.]

NOTE ON THE RESISTANCE OF MATERIALS, AS AFFECTED BY FLOW AND BY RAPIDITY OF DISTORTION.

A paper by Prof. Robert H. Thurston, Member of the Society. Presented March 1, 1876.

The effect of the "flow of metals" and of the force of polarity described by Professor Henry, in modifying their resistance to external stress and their strain, was alluded to by the writer in preceding Transactions, as follows:[*]

> The same molecular movement or flow which rearranges the internal force and relieves internal strain may be a phase of that viscosity which Vicat supposed might in time permit rupture of metal subjected to stress nearly approaching its original ultimate resistance, the one action being a more immediate result than the other, and the latter producing its effect, even when cohesive force may have been actually intensified.

It was noted, however, that in all cases in which wrought iron and steel had been subjected to stress exceeding the elastic limit the metal had exhibited no tendency to flow, and that, in nearly every case observed, an actual "elevation of the elastic limit by strain" had taken place. No experiment had then been made by the writer in which the same sample had exhibited both the elevation of the elastic limit by strain and the phenomenon of flow.

Since that time, when experimenting upon copper, strain-diagrams produced automatically have been observed to exhibit this double effect. The elevation of the elastic limit has occurred in the earlier part of the test, and, at a later period, the strain-diagram exhibits flow, the metal yielding under a gradually decreasing stress. The progressive distortion, which had never been observed by the writer in iron or steel, has, since the date of the paper, been frequently noted in other materials. For example, the following are a few illustrations:[†]

TESTS BY TORSION.

No. of test.	Material parts.		Time under stress.	Angle of torsion.	Fall of pencil.	Remarks.
	Tin.	Copper.				
*1	....	....	40 hours ..	° 65	0.06 inches..	Recovered after further distortion of 1°.
*2	100	....	1 hour ...	180	0.1 inch....	Recovered in 8°.
*3	....	....	2 hours ..	280	0.1 inch....	Recovered in 80°.
4	99.44	0.56	12 minutes	†380	50 per cent..	Did not recover.
5	98.89	1.11	....	....	....	Behaved like No. 4.
6	Alloy.		....	58	0.2 inches..	Did not recover.

* Same piece. † Taking elasticity line.

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[*] LXXXII. On the Mechanical Properties of Materials of Construction. Vol. III, page 13.

[†] Selected from the record books of the Mechanical Laboratory of the Stevens Institute of Technology.

TESTS BY TRANSVERSE STRESS—WITH DEAD LOADS.

Samples 1 × 1 × 22 inches.

No. of test.	Material parts.		Load.	Deflection.	Time.	Increased deflection.	Breaking weight.
	Tin.	Copper.					
			Pounds.	*Inches.*		*Inches.*	*Pounds.*
7	....	100	600	0.534	5 minutes	0.009	650
8	1.9	98.1	475	1.762	3 minutes	0.291	....
			500	2.108	3 minutes	0.488	500
9	7.2	92.8	950	0.348	5 minutes	0.081	1,350
10	10.	90.	950	0.395	5 minutes	0.021	....
			1,485	8.447	13 minutes	4.087	1,485
11	90.3	9.7	100	0.085	10 minutes	0.021	....
			120	0.140	10 minutes	0.055	....
			140	0.221	10 minutes	0.098	....
			140	0.319	10 minutes	0.038	....
			140	0.357	40 hours..........	0.920	....
			100	1.294	10 minutes	0.025	....
			160	1.320	1 day............	1.000	....
			160	2.320	1 day............	1.000	....
			160	3.320	1 day............	1.000	160
12	98.89	1.11	90	0.243	5 minutes	0.063	....
			120	0.736	15 minutes	1.055	....
			120	1.791	30 minutes	0.748	....
			120	2.539	45 minutes	0.595	....
			120	3.134	12 hours..........	8.000	120
13	100	....	80	0.218	5 minutes	0.064	110

Metals having a composition intermediate between these extremes have not been observed to exhibit flow or to increase deflection under a constant load.

Tests by tension with similar materials exhibit similar results, and these observations and experiments thus seem to confirm the remarks of the writer as above quoted, and to indicate that, under some conditions, the phenomena of flow and of elevation of the elastic limit by strain may be coexistent, and that progressive distortion may occur with "viscous" metals.

The paper referred to enunciated a principle which had been deduced from experiments on wrought iron, which is, if possible, of more vital importance to the engineer than the facts just given, viz: "That the time during which applied stress acts is an important element in determining its effects, not only as an element which modifies the effect of the *vis viva* of the attacking mass and the action of the inertia of the piece attacked, but also as modifying seriously the conditions of production and relief of internal strain by even simple stresses."*

It was then shown, by autographic strain-diagrams, that some materials yield the more readily the more rapidly the distortion and rupture are produced, their resistance varying in some inverse ratio with the rapidity of change of form. It was further suggested that this action might be closely related to the opposite phenomenon of the elevation of the elastic limit by strain. An explanation was offered in the theory that, with rapid distortion, insufficient time is allowed for the relief of internal strain in materials capable of exhibiting that condition. It was further remarked that "the most ductile substances may exhibit similar behavior, when fractured by shock or by any suddenly-applied force, to substances which are comparatively brittle," and illustrations were given of such behavior, and the precautions to be taken by the engineer, in view of this important modification of the resistance of materials by velocity of rupture, were stated.

The writer has continued his experimental researches, with occasional interruption, since that time, and has found the above-given statements confirmed, and that relations exist between these phenomena of strain and the time under stress, which may properly be stated here as complementary of the principles already published in the two preceding notes which have appeared in Transactions.*

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* Vol. III, page 30.

Should it be true, as suggested by the writer, that the cause of the decreased resistance, sometimes observed with increased velocity of distortion, is closely related to the cause of the elevation of the elastic limit by strain,† it would seem a simple corollary that *materials so inelastic, and so viscous as to be incapable of becoming internally strained during distortion, should offer greater resistanee to rapid than to slowly-produced distortion*, in consequence of their inability to "flow" so rapidly as to reduce resistance by such fluxion at the higher speed, or by correspondingly reducing the fractured section. This principle has been shown, by a large number of experiments, to be frequently, if not invariably, the fact. Copper, tin, and other inelastic and ductile metals and alloys are found to exhibit this behavior, and are therefore quite opposite in this respect to ordinary wrought iron and worked steel.

The writer has noted the fact that very soft wrought iron does not always exhibit an observable elevation of the elastic limit by strain, and Commander L. A. Beardslee, U. S. N.,‡ has recently observed that the softest and most ductile specimen of iron yet tested by him at the Washington Navy Yard exhibited a perceptible increase of resistance with a considerable increase of rapidity of extension. This metal was peculiar in its softness and extreme extensibility. All the irons of commerce appear to belong to the other class.

The records of the Mechanical Laboratory of the Stevens Institute of Technology frequently illustrate the proposition that metals which gradually yield under a constant load offer increased resistance with increased rapidity of rupture.

The curves of deflections of a considerable number of ductile metals and alloys are very smooth when the time during which each load has been left upon them is the same; but whenever that time has been variable the curve has been irregular. Bars of such metals broken by transverse stress give a greater resistance to rapidly-increasing stress than to stress slowly intensified. Two pieces of tin from the same bar were broken by tension, the one rapidly and the other slowly. The first broke under a load of 2,100 and the latter of 1,400 pounds. The example illustrates well the very great difference which is possible in such cases, and seems to the writer to indicate the possibility in extreme cases of obtaining results which may be fatally deceptive when the time of rupture is not noted.

The depression of the elastic limit has been observed previously in materials, but less attention has been paid to it than the importance of the phenomenon would seem to demand. The accompanying plate exhibits the strain-diagrams produced by plotting the results of experiments.§ They are selected as typical examples, and as representing the two classes of materials described.

In making the experiments the bar was mounted on cylindrical steel bearings, which were themselves supported on accurately planed level surfaces, and the deflection was produced by means of a powerful screw and a large hand-wheel. The weight was measured by a Fairbanks scale combination, and the deflections and sets by a special measuring apparatus* which reads to 0.0001 inch, with an error of 0.000741. Touch is indicated by a delicate Stackpole level. The measuring instrument was unaffected by the forces tending to distort the straining apparatus. The deflecting force was adjusted by the scale-beam. The bar being in place, the weight to be put on it was set off on the scale-beam, and the screw was carefully turned until, by its pressure on the middle of the bar, the scale-beam slowly rose and vibrated about the middle of its range, which point was indicated by a pointer at the end of the beam, traversing a fine-line scale on the frame. When the adjustment had become satisfactory the deflection was read off and the beam usually released, in order that the set might be observed. It was then again deflected by a heavier weight. Occasionally the bar was left thus strained, and with a constant deflection, for a considerable period of time, and the change of effort exerted by it noted at frequent intervals. In all such cases the scale-beam gradually drooped, and a decreased effort to effect restoration of form was indicated. When the beam had fallen, the weight was pushed back until the beam arose and vibrated about the center line again, and the weight and time were recorded. This was repeated as the beam exhibited less and less loss of power of restoration, and when this decrease of effort no longer exhibited itself a new series of deflections was produced.

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* XLI. Vol. II, page 239. CXV. Vol. IV, page 334.

† Transactions, Vol. III, page 363.

‡ Whose work has been referred to in earlier papers.

§ Made and recorded in the Mechanical Laboratory of the Stevens Institute of Technology.

The bar No. 599, which was quite ductile, exhibited an unchanged law of relation of amount of deflection to intensity of deflecting force, and, as shown by the diagram, the curve representing its test pursued the same general direction after one of these "time-tests" as before.

The loss of effort at 163 pounds is seen to have been about 20 pounds, the deflection amounting to 0.0347 inch, and the effort falling from 163 to 143 pounds. At 403 pounds the loss of restorative force is about the same; the figures fall from 403 to 333 pounds, the deflection being held constant at 0.0886 inch, again from 333 to 302 pounds at a deflection of 0.0896, and still again from 1,233 to 1,137 pounds at a deflection of 0.5209 inch.

Before the bar, under further deflection, had quite regained its original resisting power, the "time-test" was repeated, the deflection amounting to 0.5456 inch, and the weight applied being 1,233 pounds. The result noted was quite unanticipated. The effort steadily decreased at a varying rate, which is indicated by the diagram of time and loads, and the bar finally snapped sharply, and the two halves fell upon the floor. The effort had decreased to 911 pounds. The deflection was precisely what it had been under the load of 1,233 pounds. The beam had balanced at 911 pounds for about three minutes when the fracture took place. An assistant was sitting fifteen or twenty feet from the machine at the instant, but no one had approached the machine after the last adjustment of the weight.

This is a case without parallel in the experience of the writer, and its conclusion indicates a possibility of depreciation in resisting power of the class of metals of which tin has been taken as the type, which depreciation, in the present state of our knowledge of the properties of such metals in this regard, it may be safest to assume to be a source of danger in some cases in which the load approaches the maximum resisting power of the piece. This illustrates the case of progression of flow until the section most strained has been weakened to the point of actual molecular disruption, which disruption would seem to have been here produced by the effort of other and less injured portions to resume their original positions, and to straighten the two halves of the bar. It would seem that such action should be determined by flow occurring in a somewhat ductile but still somewhat elastic metal.

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* Made to the order of the writer, by Messrs. Brown & Sharpe.

The strain-diagram of this bar is seen to be nearly hyperbolic; but the law of Hooke, *ut tensio sic vis*, holds good, as usual, up to a point at which the load is about one-half the maximum. The curve of times and loads exhibits the rate of loss of effort while the bar was finally held at a deflection of 0.5456 inch, the load being carefully and regularly reduced as the effort diminished from 1,233 to 911 pounds, at which latter figure the bar broke. The curve is a very smooth one. The following is the record of the test:

BAR No. 599.

90 parts zinc, 10 parts copper: 1 × 0.992 × 22 inches.

Load.	Deflection.	Set.	Load.	Deflection.	Set.	Load.	Deflection.	Set.
Pounds.	*Inches.*	*Inches.*	*Pounds.*	*Inches.*	*Inches.*	*Pounds.*	*Inches.*	*Inches.*
23	0.0033	....	363	0.0781	....	3	....	0.0336
43	0.0078	....	403	0.0881	....	643	0.1641	....
63	0.0127	....	3	....	0.0079	803	0.2149	....
103	0.0225	....	403	0.0886	....	1,003	0.3178	....
143	0.031	....	Resistance fell in 8 h. 30 m.			1,103	0.3921	....
163	0.0347	....	to 333	0.0886	....	1,203	0.481	....
Resistance fell in 15 h. 25 m.			3	....	0.0246	1,233	0.5209	....
to 143	0.0347	....	333	0.0896	....	Resistance fell in 15 m.		
3	....	0.0039	Resistance fell in 15 h.			to 1,137	0.5209	....
163	0.0391	....	to 302	0.0896	....	3	....	0.2736
203	0.0471	....	303	0.0876	....	1,137	0.5131	....
243	0.0544	....	403	0.1072	....	1,233	0.5456	....
283	0.0611	....	503	0.1282	....			
323	0.0692	....	603	0.1521	....			

The bar was left under strain $11^h\ 22^m$ a. m., and the effort to restore itself measured at intervals, as follows:

HOUR.—$11^h\ 37^m$; $11^h\ 50^m$, a. m.; $12^h\ 2^m$; $12^h\ 8^m$; $12^h\ 25^m$; $12^h\ 39\frac{1}{2}^m$; $12^h\ 53\frac{1}{2}^m$; $12^h\ 58\frac{1}{2}^m$; $1^h\ 20^m$, p. m.

EFFORT.—1,133; 1,093; 1,070; 1,063; 1043; 1,023; 1,003; 993; 911 pounds.

At $1^h\ 23^m$ p. m. the bar broke.

An example of somewhat similar behavior, but exhibited by a metal of very different quality, is shown on the next page.

This bar was hard, brittle, and elastic, but must apparently be classed with tin in its behavior under either continued or intermitted stress.

There seems to the writer to exist a distinction, illustrated in these cases, between that "flow" which is seen in these metals, and that to which has been attributed the relief of internal stress and the elevation of the elastic limit by strain and with time.

This last phenomenon—the exaltation of the elastic limit by strain—has been observed very strikingly by the writer in the deflection of iron bars by transverse stress. The plate exhibits the strain-diagrams obtained by transverse deflection of 4 bars of ordinary merchant wrought iron, which were all cut from the same rod. Of these, two were tested in the machine above described, in which the deflection remains constant when the machine is untouched while the load gradually decreased, or, more properly, while the effort of the bar to regain its original form decreases. The other two were tested by dead loads, the load remaining constant while the deflection may vary when the apparatus is left to itself. (The record is given on pages 11–14.)*

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* Pages 462–464 of this report.

BAR No. 596.

75 parts zinc, 25 parts copper; second casting; 0.985 × 0.985 × 22 inches.

Load.	Deflection.	Set.	Load.	Deflection.	Set.	Load.	Deflection.	Set.
Pounds.	*Inches.*	*Inches.*	*Pounds.*	*Inches.*	*Inches.*	*Pounds.*	*Inches.*	*Inches.*
23	0.0057	....	423	0.073	....	to 473	0.0866	....
63	0.0142	....	463	0.0799	....	3	....	0.0092
103	0.0207	....	503	0.0866	....	503	0.0894	....
143	0.0275	....	3	....	0.0014	543	0.0952	....
183	0.0346	....	503	0.0866	....	583	0.1012	....
223	0.0414	....	Resistance fell in 5 h.			603	0.1042	....
263	0.0485	....	to 489	0.0866	....	623	0.1075	....
303	0.0549	....	3	....	0.0074	643	0.1102	....
343	0.0610	....	489	0.0866	....	663	0.1136	....
383	0.0669	....	Resistance fell in 13 h. 30 m.			Broke 5 seconds after with ringing sound.		

These two pairs of specimens were broken; one in each set by adding weight steadily until the end of the test, so as to give as little time for elevation of elastic limits as was possible; and one in each set by intermittent stress, observing sets, and the elevation of the elastic limit.

If the long-known effects of cold-hammering, cold-rolling, and wire-drawing in stiffening, strengthening, and hardening some metals can be, as the writer is inclined to believe, attributed in part to this molecular change, as well as to simple condensation and closing up of cavities and pores, this exaltation of the elastic limit by distortion under externally applied force has now been shown to occur in iron and in metals of that class in tension, torsion, compression, and under transverse strain.

Referring to the plate, it will be seen that there is exhibited the action in the latter case even more fully and strikingly than in the record above given, and a study of these typical examples cannot fail to prove both interesting and instructive.

TESTS OF WROUGHT-IRON BARS BY TRANSVERSE STRAIN.

Samples 1 inch square, 28 inches long; 22 inches between supports.

No. 648.—TESTED IN FAIRBANKS' MACHINE.

Load.	Deflection.	Set.	Load.	Deflection.	Set.	Load.	Deflection.	Set.
Pounds.	*Inches.*	*Inches.*	*Pounds.*	*Inches.*	*Inches.*	*Pounds.*	*Inches.*	*Inches.*
103	0.0132	....	Resistance fell in 2 h.			1,831	0.8471	....
203	0.0244	....	to 1,187	0.121	....	2,003	0.8641	....
Resistance fell in 13 h. 35 m.			3	....	0.0096	2,071	0.8819	....
to 199	0.0244	....	1,203	0.1226	....	2,081	0.9396	....
303	0.0342	....	1,243	0.1266	....	3	....	0.7576
403	0.0428	....	1.283	0.1301	....	2,081	0.9886	....
Resistance fell in 1 h. 30 m.			1,323	0.1354	....	Resistance fell in 21 h. 39 m.		
to 399	0.0428	....	1,741	0.7081	....	to 1,871	0.9886	....
3	....	0.0042	1,911	0.7246	....	3	....	0.8148
503	0.0528	....	1,921	0.7566	....	1,911	0.9904	....
603	0.0619	....	3	....	0.5746	2,083	1.0106	....
Resistance fell in 4 h.			1,921	0.7746	....	2,121	1.0496	....
to 598	0.0619	....	Resistance fell in 21 h. 48 m.			2,131	1.0911	....
803	0.0806	....	to 1,767	0.7746	....	3	....	0.9021
Resistance fell in 15 h. 15 m.			3	....	0.6028	2,131	1.1316	....
to 789	0.0806	....	1,767	0.7726	....	1,363	0.1421	....
903	0.0907	....	1,931	0.7876	....	1,403	0.1504	....
1,003	0.0995	....	1,995	0.8036	....	3	....	0.0196
Resistance fell in 5 h. 20 m.			2,001	0.8266	....	1,403	0.1522	....
to 987	0.0995	....	3	....	0.6451	Resistance fell in 3 m.		
3	....	0.0049	2,001	0.8498	....	to 1 387	0.1522	....
1,203	0.1197	....	Resistance fell in 21 h. 30 m.			Resistance fell in 2 h. 25. m.		
3	....	0.0071	to 1,831	0.8498	....	to 1,361	0.1522	....
1,203	0.121	....	3	....	0.6780			

TESTS OF WROUGHT-IRON BARS BY TRANSVERSE STRAIN—Continued.

Load.	Deflection.	Set.
Pounds.	*Inches.*	*Inches.*
Resistance fell in 39 h. 5 m.		
to 1,329	0.1522	....
3	....	0.0246
1,329	0.1451	....
1,403	0.1522	....
1,483	0.16	....
1,523	0.1647	....
1,563	0.1761	....
1,603	0.2548	....
3	....	0.1091
1,603	0.287	....
Resistance fell in 6 h. 8 m.		
to 1,457	0.287	....
3	....	0.1451
1,457	0.2863	....
1,603	0.3016	....
1,703	0.3921	....
3	....	0.2431
1,703	0.4301	....
Resistance fell in 20 h. 50 m.		
to 1,541	0.4301	....
3	....	0.2846
1,541	0.4296	....
Resistance fell in 47 h. 37 m.		
to 1,869	1.1316	....
3	....	0.958
1,941	1.1358	....
2,131	1.1551	....
2,181	1.1686	....
2,201	1.1981	....
2,211	1.2356	....
3	....	1.0361
Resistance fell in 9 h.		
to 1,997	1.2356	....
3	....	1.1158
2,001	1.3016	....
2,211	1.3326	....
2,231	1.3656	....
2,237	1.3936	....
3	....	1.1946
2,241	1.4441	....
Resistance fell in 13 h. 50 m.		
to 2,041	1.4441	....
3	....	1.2538
2,041	1.4421	....
2,241	1.4631	....
2,281	1.4821	....
2,301	1.5216	....
2,311	1.5531	....
3	....	1.3436
2,311	1.6166	....
Resistance fell in 8 h. 8 m.		
to 2,091	1.6166	....
3	....	1.4181
2,091	1.6166	....
1,603	0.4346	....
1,711	0.4456	....
1,753	0.4513	....
1,781	0.4651	....
Resistance fell in 6 h. 3 m.		
to 1,661	0.4651	....
3	....	0.3106
1,675	0.4676	....
1,787	0.4808	....
1,811	0.5446	....
3	....	0.3771
1,811	0.5661	....
Resistance fell in 46 m.		
to 1,675	0.5661	....
Resistance fell in 17 h.		
to 1,661	0.5661	....
3	....	0.4081
1,661	0.5645	....
1,801	0.578	....
1,861	0.5886	....
1,877	0.6034	....
1,891	0.6626	....
3	....	0.4938
1,891	0.7001	....
Resistance fell in 10 s.		
to 1,801	0.7001	....
Resistance fell in 6 m.		
to 1,737	0.7001	....
Resistance fell in 5 h. 23 m.		
to 1,721	0.7001	....
3	....	0.5406
2,311	1.6466	....
2,341	1.6996	....
2,351	1.7321	....
3	....	1.5196
2,351	2.0446	....
Resistance fell in 16 h.		
to 2,135	2.0446	....
3	....	1.8441
2,135	2.0431	....
2,355	2.0646	....
2,391	2.0736	....
2,411	2.1136	....
3	....	1.8964
2,411	2.1451	....
Resistance fell in 8 h. 35 m.		
to 2,238	2.1451	....
Gradually reduced strain		
to 3*	....	1.9266
Gradually increased strain		
to 2,238*	2.1336	....
2,411	2.1516	....
2,491	2.1811	....
2,501	2.2121	....
3	....	1.9886
2,501	2.2471	....
Resistance fell in 14 h. 10 m.		
to 2,295	2.2471	....
3	....	2.0331
2,295	2.2456	....
2,541	2.2762	....
2,561	2.3102	....
3	....	2.0763
2,561	2.35	....
Resistance fell in 6 h. 18 m.		
to 2,369	2.35	....
3	....	2.1402
2,369	2.3587	....
2,551	2.3782	....
2,571	2.3854	....
2,591	2.4287	....
3	....	2.1952
2,591	2.5044	....
Resistance fell in 15 h. 4 m.		
to 2,371	2.5044	....
3	....	2.2842
2,371	2.5022	....
2,591	2.5247	....
2,611	2.5334	....
2,631	2.5927	....
3	....	2.3577
2,631	2.653	....
Resistance fell in 8 h. 2 m.		
to 2,371	2.653	....
3	....	2.4227
2,371	2.6532	....
2,631	2.6833	....
2,651	2.6992	....
2 661	2,7307	....
3	....	2.4987
2.661	2.8324	....
Resistance fell in 61 h. 32 m.		
to 2,363	2.8324	....
3	....	2.5924
2,363	2,8286	....
2,685	2.8627	....
2,701	2,871	....
2,710	2,8917	....
2,720	2.9297	....
3	....	2.647
2,720	2.9692	....
Resistance fell in 5 h. 48 m.		
to 2,483	2.9692	....
3	....	2,7357
Bar removed: test ended.		

* Gradually rednced strain to 3 pounds, taking a number of readings; then gradually increased it to 2,238 pounds, taking readings corresponding to former ones; found that increase of deflection was proportional to increase of load.

No. 649.—TESTED IN FAIRBANKS' MACHINE.

Load.	Deflection.	Load.	Deflection.	Load.	Deflection.	Load.	Deflection.
Pounds.	*Inches.*	*Pounds.*	*Inches.*	*Pounds.*	*Inches.*	*Pounds.*	*Inches.*
103	0.0139	900	0.0889	1,462	0.1505	In 2¾ m. was	0.3629
200	0.0238	1,000	0.0982	1,480	0.1569	1,620	0.3704
300	0.0328	1,100	0.1081	1,500	0.1619	1,640	0.3831
405	0.0425	1,200	0.1171	1,520	0.1709	In 6 m. was	0.4404
500	0.0519	1,300	0.1279	1,540	0.1804	1,660	0.4479
600	0.0602	1,400	0.1398	1,560	0.2078	*b*1,680	0.4599
700	0.0689	1,420	0.1435	1,580	0.2429	....	....
800	0.0787	1,442	0.1472	*a*1,600	0.2854	2,350	5.577

a At 1,600 pounds the beam sank instantly; ran the pressure-screw down so as to keep the beam balanced for 2¾ m., with increase of deflection as noted.

b At 1,680, ran pressure-screw rapidly but steadily down, moving the poise along the beam to keep it balanced. The beam vibrated up and down, falling or rising instantly as the wheel was turned slower or faster. The resistance reached a maximum of 2,850 pounds, when the deflection was 5.577 inches.

No. 650.—TESTED BY DEAD LOADS.

Load.	Deflection.	Load.	Deflection.	Load.	Deflection.	Load.	Deflection.
Pounds.	*Inches.*	*Pounds.*	*Inches.*	*Pounds.*	*Inches.*	*Pounds.*	*Inches.*
100	0. 015	400	0. 0425	800	0. 0858	1, 400	0. 1749
200	0. 0229	600	0. 0638	1, 200	0. 1456	[c]1, 500	0. 2143

[c] At 1,626, the reading was not taken. Weights as follows were rapidly added, 4 or 5 pieces each minute, as follows: 82, 25, 42, 15, 16, 10, 15.5, 16, 25, 25, 25, 13, 11, 5, 16.27, 62, 40.5, 61, 45, 62=2,260.5 pounds. The bar sank rapidly, its side pressure splitting the wood which confined the mandrels. The set measured after the bar was removed, 2.5 inches. The total deflection is calculated as follows: the elasticity of the bar remaining the same, the increase of deflection over set is directly proportional to the load. (This is shown by the parallelism of the elasticity lines with the original line within the elastic limit.) Thus, at 800 pounds the set was inappreciable, deflection 0.0858; whence 800: 0.0858:: 2,260: 0.242 difference of deflection and set; set was 2.5, hence calculated deflection 2.742 inches.

No. 651.—TESTED BY DEAD LOADS.

Load.	Deflection.	Load.	Deflection.	Load.	Deflection.	Load.	Deflection.
Pounds.	*Inches.*	*Pounds.*	*Inches.*	*Pounds.*	*Inches.*	*Pounds.*	*Inches.*
100	0. 0158	In 5 h. 4 6m. was	0. 6598	In 48 h. 30 m. was	1. 9245	2, 452	3. 0732
200	0. 0275	1, 700	0. 67	2, 222	1. 9379	2. 484	3. 0812
400	0. 0489	In 3 m. was	0. 6716	2, 288	2. 1386	In 39 h. 40 m.	4. 2591
600	0. 0709	In 16 h. was	0. 7615	In 12 m. was	2. 9535	In 43 h. 20 m.	4. 2591
803	0. 0913	1, 800	0. 771	2, 266	2. 9928	2, 513	4. 2623
1, 000	0. 1141	1, 900	1. 0904	In 17 m. was	3. 0157	2, 556	4. 267
1, 210	0. 1394	In 3 h. 15 m. was	1. 8567	In 3 h. 37 m. was	3. 0236	In 4 h. 20 m.	4. 2749
1, 400	0. 1701	In 45 h. 45 m. was	1. 8709	2, 288	3. 0.9	2, 589	4. 2749
1, 500	0. 2465	2, 005	1. 8787	2, 350	3. 0426	In 48 h. was	4. 6591
In 8 m. was	0. 4307	In 3 h. was	1. 8819	2, 370	3. 0433	In 61 h. 30 m. was	4. 6701
1, 600	0. 489	2, 052	1. 8886	In 25 h. 15 m. was	3. 0677	Weights reached support. Test was ended.	
In 6 m. was	0. 6504	2, 115	1. 8921	2, 422	3. 0701		

The strain-diagrams exhibited in the plate do not present to the eye one of the most important distinctions between the two classes of metals. As seen by study of these diagrams, both classes, when strained by flexure, gradually exhibit less and less effort to restore themselves to their original form.

In the case of the tin-class, this loss of straightening power seems often to continue indefinitely, and, as in one example here illustrated, even until fracture occurs.

With iron and the class of which that metal is typical this reduction of effort becomes gradually less and less rapid, and finally reaches a limit after attaining which the bar is found to have become strengthened, and the elastic limit to have become elevated. In this respect, the two classes are affected by time of strain in precisely opposite ways.

The plate exhibits, even better than the record, the superior ultimate resistance of the bars which have been intermittently strained, as well as the elevation of the elastic limit. This parallelism of the "elasticity lines" obtained in taking sets shows that the modulus of elasticity is unaffected by the causes of elevation of the elastic limit.

Evidence appealing directly to the senses has been presented in the course of experiment on the second class of metals of the intra-molecular flow. When a bar of tin is bent, it emits while bending the peculiar crackling sound familiarly known as the "cry of tin." This sound has not been observed hitherto, so far as the writer is aware, when a bar has been held flexed and perfectly still. In several cases recently, in experiments on flexure[*] of metals of the second class, bars held at a constant deflection have emitted such sounds hour after hour, while taking set and losing their power of restoration of shape.

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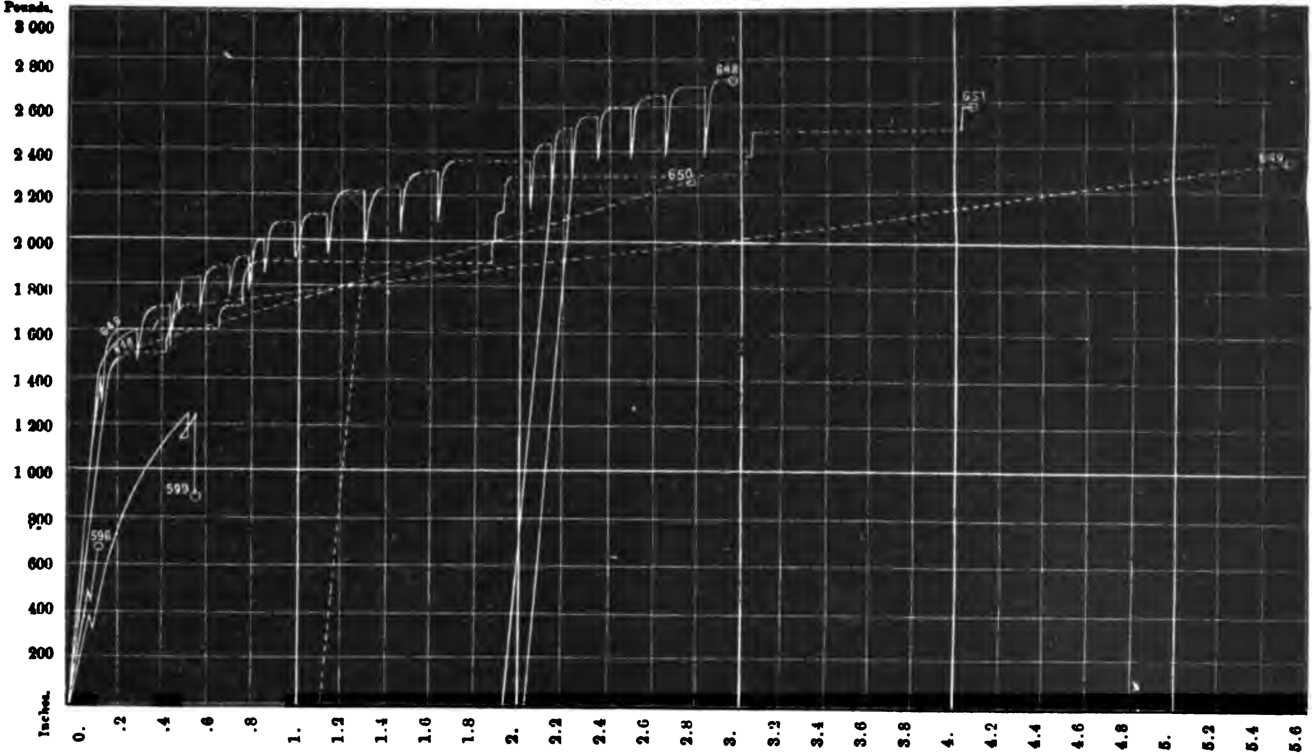
[*] Made in the Mechanical Laboratory of the Stevens Institute of Technology.

STRAIN DIAGRAMS

OF FOUR BARS OF WROUGHT IRON, AND TWO OF COPPER-ZINC ALLOYS TESTED BY TRANSVERSE STRAINS.

ROBERT H. THURSTON.



During some of the experiments made, a very marked illustration of the decrease of set with time, which has been observed and described by Prof. W. A. Norton, has been noted, and the recovery of straightening power in the deflected bar has sometimes been strikingly large, amounting to nearly 30 pounds in 15 minutes. A record of one of these bars is—

BAR No. 563.

17.5 parts copper, 82.5 parts tin; 0.986×0.993×22 inches.

Load.	Deflection.	Set.	Load.	Deflection.	Set.	Load.	Deflection.	Set.
Pounds.	*Inches.*	*Inches.*	*Pounds.*	*Inches.*	*Inches.*	*Pounds.*	*Inches.*	*Inches.*
10	0.0027	....	140	0.0804	....	300	0.4597	....
20	0.007	....	180	0.1343	....	5	.. ..	0.3084
40	0.0153	....	200	0.1666	....	Set decreased in 2 h. 20 m.		0.2845
60	0.0256	....	5	....	0.0821			
80	0.0365	....	200	0.1798	....	to 300	0.5332	....
100	0.0499	....	240	0.2503	....	310	Bar broke in putting on strain.	
5	....	0.0092	280	0.3762	....	....		

After 300 pounds had been placed on the bar, and the reading taken, the screw was run back till the beam just balanced at 5 pounds, the pressure-block attached to the screw barely touching the bar. The set was then read, as above, 0.3084 inch, the beam slowly rising. The pressure-screw was then run back till beam again balanced at 5 pounds, and the set measured 0.3022 inch; the time was 2 minutes. The beam again rose, poise on beam was pushed forward and balanced at 10 pounds; the time was 2 minutes. In two minutes more beam balanced at 14 pounds. The pressure-screw was again run back till beam balanced at 5 pounds, and the set measured 0.2998 inch. The beam rose again at 11 hours 37 minutes, a. m. In 2 minutes it balanced at 10 pounds, in 10 minutes at 16 pounds, and in 29 minutes at 23 pounds. The beam was again balanced at 5 pounds, set measured 0.2902 inch. The beam rose in 4 minutes. In 29 minutes the beam balanced at 14 pounds, and in 65 minutes more it balanced at 20 pounds. The beam was again balanced at 5 pounds, and the set measured 0.2845 inch. The total decrease of set in 2 hours 20 minutes was 0.3084—0.2845=0.0239 inch. Then replaced 300 pounds, and read deflection 0.5332 inch; increased the pressure, but the bar broke before 310 pounds was reached.

AMERICAN SOCIETY OF CIVIL ENGINEERS.

[Incorporated 1852.]

THE RATE OF SET OF METALS SUBJECTED TO STRAIN FOR CONSIDERABLE PERIODS OF TIME.

A paper by Prof. Robert H. Thurston, Member of the Society. Read December 6, 1876.

SECTION I.[*]—*On the observed decrease of resistance at a fixed distortion.*—The writer has, in a preceding paper,[†] shown by reference to experimental researches in which he had then engaged, that some classes of metals, as ordinary iron and steel, when subjected to strain and distortion by a force exceeding the resistance of the material within the elastic limit, take a set and are stiffened by that act, and exhibit an exaltation of the elastic limit. It was also shown that other classes, like tin and similarly viscous and ductile materials, exhibit flow and a depression of their limits of elasticity when similarly treated.* It was further shown that the former class, when subjected to loads even approaching their ultimate strength, took a certain set and remained apparently indefinitely without further distortion; while the second class, under very moderate loads, frequently exhibited a gradual yielding, a progressive distortion, until fracture took place, sometimes under stresses which were but a fraction of those which were found required to break such metals quickly, and when time was not allowed for flow to occur. It was noted that increase of rapidity of distortion and fracture produced increase of resistance in the latter, or "tin class," and decrease of resisting power in the first, or "iron class," and *vice versa.*

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[*] Prepared July, 1876.

[†] CXXIII. Note on the resistance of materials as affected by flow, and by rapidity of distortion, vol. v, page 199; also "Van Nostrand's Engineering Magazine," September, 1876, and "Engineering" (London), December 29, 1876.

The writer has since instituted experiments upon metals of both classes to determine how rapidly set, in each class, took place; the earlier experiment just referred to having confirmed a suspicion long existing among engineers and experimentalists that the phenomenon was a molecular change as well as of the mass, and that time was required for its complete development. Professor Norton has also shown by experiment that this set is partially temporary, the bar relieving itself of distortion in some degree on removal of the load. Both that experimenter and the writer had detected some peculiar variations of form during this recovery, and the experiments of the latter, as detailed in the preceding paper, exhibited at times a gradual recovery of straightening power in a confined and flexed bar. The following will be found interesting, and perhaps important, as showing how these molecular changes progress:

Bars were prepared of square section, 1 inch in breadth and depth, and 22 inches in length between bearings. They were flexed in a machine† for testing the resistance of materials to transverse stress, as described in the preceding paper, and the load and deflection carefully measured. As the bars were retained at a constant deflection, their effort to resume their original form gradually decreased, and the amount of this effort was from time to time noted. When this effort or resistance had become considerably decreased, the bar was released and the set measured. This operation was repeated with each, until the law of decrease of elastic resistance was detected. Curves were constructed, illustrating graphically this law, and exhibiting it more satisfactorily and more plainly than the tabular record.

The following is the record for the bars of iron, of tin, and of two alloys: The iron bar No. 648 was subjected to a load of 1,003 pounds, somewhat less than one-half its maximum, and its deflection was found to be 0.0995 inch. Removing the load, the set was 0.0049 inch. Restoring the load (1,000 pounds, + 3 pounds due to the weight of the bar), the deflection was 0.1001 inch, and the bar was held at this deflection and the decrease of resistance observed. In 25 minutes it had become 999 pounds; in 1 hour 40 minutes, 991 pounds; in 4 hours 35 minutes, 987 pounds; and in 5 hours 20 minutes, 987 pounds. The set was then found to be 0.007 inch under the weight of the bar itself.

Restoring the last-observed load, the deflection was 0.0991 inch, and the original load of 1,003 pounds increased it to 0.1003 inch.

A second trial of the same bar under a load of 1,603 pounds gave a deflection of 0.2548 inch, and a set, on removal, of 0.1091 inch. Restoring the load, the deflection became 0.287 inch, and the resistance to flexion decreased in 6 hours 3 minutes from 1,603 to 1,575 pounds, at which latter time the set was found to be 0.1451 inch. Restoring the load of 1,457 pounds, the deflection was 0.2863 inch, and the original load, 1,603 pounds being brought upon it, its deflection increased to 0.3016 inch, an increase nearly 20 per cent. above the original deflection.

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* Mr. E. H. Hewins has informed the writer since the publication of that paper that he has detected simultaneous "flow" and "exaltation of the elastic limit" in iron.

† Built for the Mechanical Laboratory of the Stevens Institute of Technology.

In the first trial the loss of stiffness, as measured by the decrease of effort to straighten itself,and which is here taken to measure the *rate of set*, is seen to have been nearly proportional to the time at first, becoming constant after 4½ hours. On the second trial, after a considerable set, produced by a heavy load, the set became constant after about one hour, and so remained to the end of the trial.

No. 655 was a bar of Queensland tin, received* from the Commisioner of that country at the Centennial Exhibition, and which was found to be remarkably pure. A load of 109 pounds gave a deflection of 0.2109 inch, and produced a set of 0.1753 inch. The same load restored deflected the bar 0.2415 inch, which deflection being retained, the effort to regain the original shape decreased in one minute from 100 to 70 pounds, in 3 minutes to 62, and in 8 minutes to 56 pounds. The original load of 100 pounds then brought the deflection to 0.3033 inch, nearly 50 per cent. more than at first.

A bar, No. 599, of copper-zinc alloy, similiarly tested, deflected 0.5209 inch under 1,233 pounds, and took a set of 0.2736 inch after being held at that deflection 15 minutes, the effort falling meantime to 1,137 pounds. Restoring the load of 1,137 pounds, the deflection became 0.5131 inch, and the original load of 1,233 pounds brought it to 0.5456 inch. The bar was now held at this deflection and the set gradually took place, the effort falling in 15 minutes to 1,133 pounds (4 per cent. more than at the first observation), in 22 minutes to 1,093, in 46 minutes to 1,063, in 63 minutes to 1,043, in 91½ minutes to 1,003, and in 118 minutes to 911 pounds, at which last strain the bar broke 3 minutes later, the deflection remaining unchanged up to the instant of fracture. This remarkable case has already been referred to in an earlier paper,† when treating of the effect of time in producing variation of resistance and of the elastic limit.

Nos. 561, copper-tin, and 612, copper-zinc, were compositions which behaved quite similarly to the iron bar at its first trial, the set apparently becoming nearly complete in the first after 1 hour, and in the second after 3 or 4 hours.

In all of these metals, the set and the loss of effort to resume the original form were phenomena requiring time for their progress, and in all, except in the case of No. 599—which was loaded heavily—the change gradually became less and less rapid, tending constantly toward a maximum.

So far as the observation of the writer has yet extended, the latter is always the case under light loads. As heavier loads are added, and the maximum resistance of the material is approached, the change continues to progress longer, and, as in the case of the brass above described, it may progress so far as to produce rupture, when the load becomes heavy, if the metal does not belong to the "iron class." The brass broke under a stress 25 per cent. less than it had actually sustained previously.

There is no evidence that iron or steel ever exhibits this treacherous and exceedingly dangerous behavior; but, on the contrary, it seems always to carry a load, once borne, however near the maximum it may be. This difference is here quite as marked as in the experiments previously reported upon the elevation and the depression of the elastic limit by strain; and no one can fail to note the value in construction of this quality of that metal which is the chief reliance of the engineer in nearly every branch of his art. These principles will find numberless applications in the practice of every member of the profession.

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*By the Mechanical Laboratory of the Stevens Institute of Technology.

† Vol. v, page 205.

The records are herewith presented, and the curves representing them shown in the Plate.

RECORDS OF EXPERIMENTS ON RATE OF SET OR DECREASE OF RESISTANCE AND INCREASE OF SET OF METALS, WITH TIME.

Bars 1 inch square; 22 inches between supports.

Time.	Load.	Loss of load.	Deflection.	Set.
	No. 648.—Wrought iron.			
		First trial.		
Minutes.	*Pounds.*	*Pounds.*	*Inches.*	*Inches.*
	1,003		0.0995	
	3			0.0049
	1,003		0.1001	
25	999	4	0.1001	
100	991	12	0.1001	
275	987	16	0.1001	
320	987	16	0.1001	
320	3			0.007
322	987		0.9910	
322	1,003		0.1003	
	2,720		2.6400	
		Second trial.		
	1,003		2.2548	
No. 561.—27.5 parts copper, 72.5 parts tin.				
	160		0.0696	
	5			0.0145
	160		0.072	
1	154	6	0.072	
3	150	10	0.072	
2,640	104	56	0.072	
4,140	100	60	0.072	
	5			0.04
	100		0.0763	
	160		0.0970	
	320		0.2200	Broke.
No. 599.—10 parts copper, 90 parts zinc.				
	1,233		0.5209	
15	1,137		0.5209	
	3			0.2736
	1,137		0.5131	
	1,233		0.5456	
15	1,133	100	0.5456	
28	1,093	140	0.5436	
40	1,070	163	0.5456	
46	1,063	170	0.5456	
63	1,043	190	0.5456	
77.5	1,023	210	0.5456	
91.5	1,003	230	0.5456	
Minutes.	*Pounds.*	*Pounds.*	*Inches.*	*Inches.*
	3			0.1081
	1,603		0.287	
1	1,521	82	0.287	
2	1,493	110	0.287	
3	1,483	120	0.287	
23	1,463	140	0.287	
53	1,461	142	0.287	
133	1,459	144	0.287	
193	1,457	146	0.287	
363	1,457	146	0.287	
363	3			0.1461
	1,457		0.2863	
	1,603		0.3016	
	2,720		2.6400	
96.5	903	240	0.5456	
118	911	322		
121	911	326		Broke.
No. 612.—47.5 parts copper, 52.5 parts zinc.				
	800		0.3332	
	3			0.1473
	800		0.3366	
5	790	10	0.3366	
25	778	22	0.3366	
120	766	34	0.3366	
480	756	44	0.3366	
1,230	751	49	0.3366	
	3			0.1686
	751		0.3364	
	800		0.3490	
	1,100			Broke.
	No. 655.—Queensland tin.			
	100		0.2109	
	3			0.1753
	100		0.2415	
1	70	30	0.2415	
8	62	38	0.2415	
8	56	44	0.2415	
	100		0.3033	
	150		Bent rapidly.	

SECTION II*.—*The observed increase of deflection under static load.*—In the preceding section the writer presented results of an investigation made† to determine the time required to produce "set" in metals belonging to the two typical classes, which exhibit, the one an exaltation and the other a depression of the elastic limit under strain.

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*Prepared November, 1876.

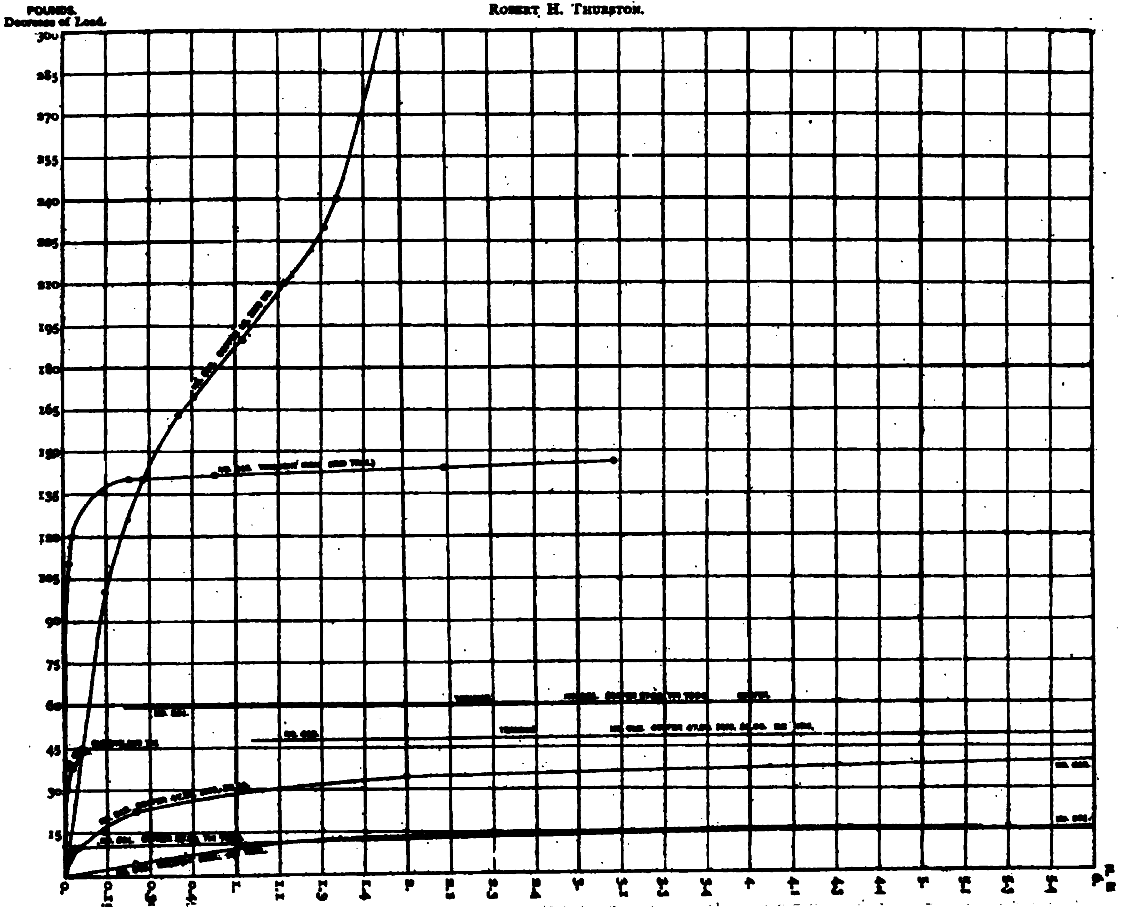
† In the Mechanical Laboratory of the Stevens Institute of Technology.

PLATE VII.

DECREASE OF RESISTANCE WITH TIME IN TRANSVERSE TESTS OF BARS OF METAL.

RATE OR SET OF BARS, 1 INCH SQUARE, 22 INCHES BETWEEN SUPPORTS.

ROBERT H. THURSTON.



The experiments there described were made by means of a testing machine, in which the test-piece could be securely held at a given degree of distortion, and its effort to recover its form measured at intervals, until the progressive loss of effort could no longer be detected, and until it was thus indicated that set had become complete.

The deductions were:

That in metals of all classes under light loads this decrease of effort and rate of set become less and less noticeable until, after some time, no further change can be observed, and the set is permanent.

That in metals of the "tin class," or those which had been found to exhibit a depression of the elastic limit with strain, a heavy load, *i. e.*, a load considerably exceeding the proof strain, the loss of effort continued until, before the set had become complete, the test-piece yielded entirely.

And that in the metals of the "iron class," or those exhibiting an elevation of elastic limit by strain, the set became a maximum and permanent, and the test-piece remained unbroken, no matter how near the maximum load the strain may have been.

The experiments here described were conducted with the same object as those above referred to. In these experiments, however, the load, instead of the distortion, was made constant, and deflection was allowed to progress, its rate being observed, until the test-piece either broke under the load or rapidly yielded, or until a permanent set was produced. It will be seen that the results of these experiments are in striking accordance with those conducted in the manner previously described. They exhibit the fact of a gradually-changing rate of set for the several cases of light or heavy loads, and illustrate the striking and important distinctions between the two classes of metals even more plainly than the preceding. The accompanying record and the strain-diagrams, which are its graphical representation, will assist the reader in comprehending the method of research and its results. All test-pieces were of one-inch square section, and loaded at the middle. The bearings were 22 inches apart.

No. 651 was of wrought iron from the same bar with No. 648, already described.* This specimen subsequently gave way under a load of 2,587 pounds. Its rate of set was determined at about 60 per cent. of its ultimate resistance, or at 1,600 pounds. Its deflection, starting at 0.489 inch, increased in the first minute 0.1047; in the second minute, 0.026; in the third minute, 0.0125; in the fourth minute, 0.0088; in the fifth minute, 0.0063; and in the sixth minute, 0.0031 inch; the total deflections being 0.5937, 0.6197, 0.6322, 0.641, 0.6473, and 0.6504 inch. In the succeeding 10 minutes the deflection only increased 0.0094 inch, or to 0.6598 inch, and remained at that point without increasing so much as 0.0001 inch, although the load was allowed to remain 344 minutes untouched. The bar had evidently taken a permanent set, and it seems to the writer probable that it would have remained at that deflection indefinitely, and have been perfectly free from liability to fracture for any length of time.

This bar finally yielded completely, under a load of 2,589 pounds, deflecting 4.67 inches.

No. 479 was a copper bar containing 3¾ per cent. of tin. Its behavior may be taken as typical of that of the whole "tin class" of metals, as the preceding illustrates the behavior of the "iron class" under heavy loads. It was subjected to two trials, the one under a load of 700 and the other of 1,000 pounds, and broke under the latter load, after having sustained it 1¼ hours. The behavior of this bar will be considered especially interesting, if its record and strain-diagram are compared with those of No. 599, previously given, which latter specimen broke after 121 minutes, when held at a constant deflection of 0.5456 inch; its resistance gradually falling from an initial amount of 1,233 pounds, to 911 pounds at the instant before breaking.

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* Vol. v, page 208.

This bar, No. 479, was loaded with 700 pounds "dead weight," and at once deflected 0.441 inch. The deflection increased 0.118 inch in the first five minutes, 0.024 in the second five minutes, 0.018 in the second 10 minutes, 0.17 in the fourth, 0.012 in the fifth, and 0.008 inch in the sixth 10-minute period, the total set increasing from 0.441 to 0.65 inch. The record and the strain-diagram show that at the termination of this trial the deflection was regularly increasing. The load was then removed and the set was found to be 0.524 inch, the bar springing back 0.126 inch on removal of the weight.

The bar was again loaded with 1,000 pounds. The first deflection which could be measured was 3.118 inches, and the increase, at first followed the parabolic law noted in the preceding cases, but quickly became accelerated; this sudden change of law is best seen on the strain-diagram. The new rate of increase continued until fracture actually occurred, at the end of 1¼ hours, and at a deflection of 4.506 inches.

This bar was of very different composition from No. 599; it is a member of the "tin class," however, and it is seen, by examining their records and strain-diagrams, that these specimens, tested under radically different conditions, both illustrate the peculiar characteristics of the class, by similarly exhibiting its treacherous nature.

No. 504 was a bar of tin containing about 0.6 per cent. of copper—the opposite end of the scale—and exhibited precisely similar behavior, taking a set of 0.323 inch under 110 pounds and steadily giving way and deflecting uninterruptedly until the trial ended at the end of 1,270 minutes, over 21 hours. This bar subsequently was, by a maximum stress of 130 pounds, rapidly broken down to a deflection of 8.11 inches.

No. 501 presents the finest illustration yet entered in the record book of the Mechanical Laboratory of the Stevens Institute of Technology. The test extended over nearly 2½ days under observation, and then left for the night, was found next morning broken. The time of fracture is therefore unknown, as is the ultimate deflection. The record is, however, sufficient to determine the law, and the strain-diagram is seen to be similar to that of the second test of No. 479, exhibiting the same tendency to the parabolic shape and the same change of law and reversal of curvature preceding final rupture, and illustrates even more strikingly the fact that this class of metals is not safe against final rupture, even though the load may have been borne a considerable time, and have apparently been shown, *by actual test*, to be capable of sustaining it. A strain-diagram of each of the latter two bars is exhibited on a reduced scale to present to the eye more strikingly this important characteristic.

A comparison of the records and the strain-diagrams with those of Section I, in illustration of the behavior of the two classes of metals under constant deflection, is most instructive. The light thus thrown upon the phenomena of distortion and fracture may be of great service to all who are engaged in construction. It will be necessary to make many experiments to determine under what fraction of their ultimate resistance to rapidly applied and removed loads, the members of the "tin class"—the viscous metals—will be safe under static permanent loads. Their behavior under shocks of various intensities remains also

PLATE VIII.

INCREASE OF DEFLECTION WITH TIME IN TRANSVERSE TESTS OF BARS OF METAL.

RATE OF SET OF BARS, 1 INCH SQUARE 22 INCHES, BETWEEN SUPPORTS.

ROBERT H. THURSTON.

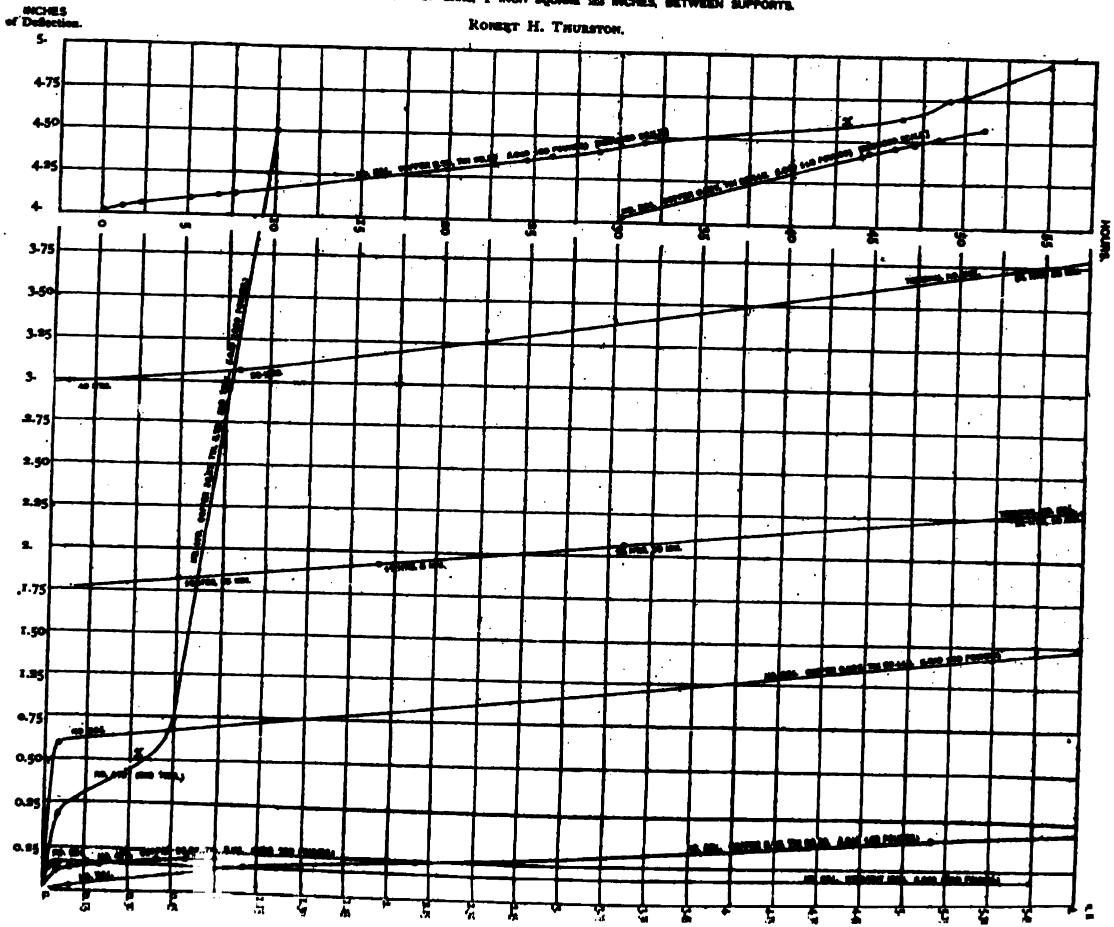
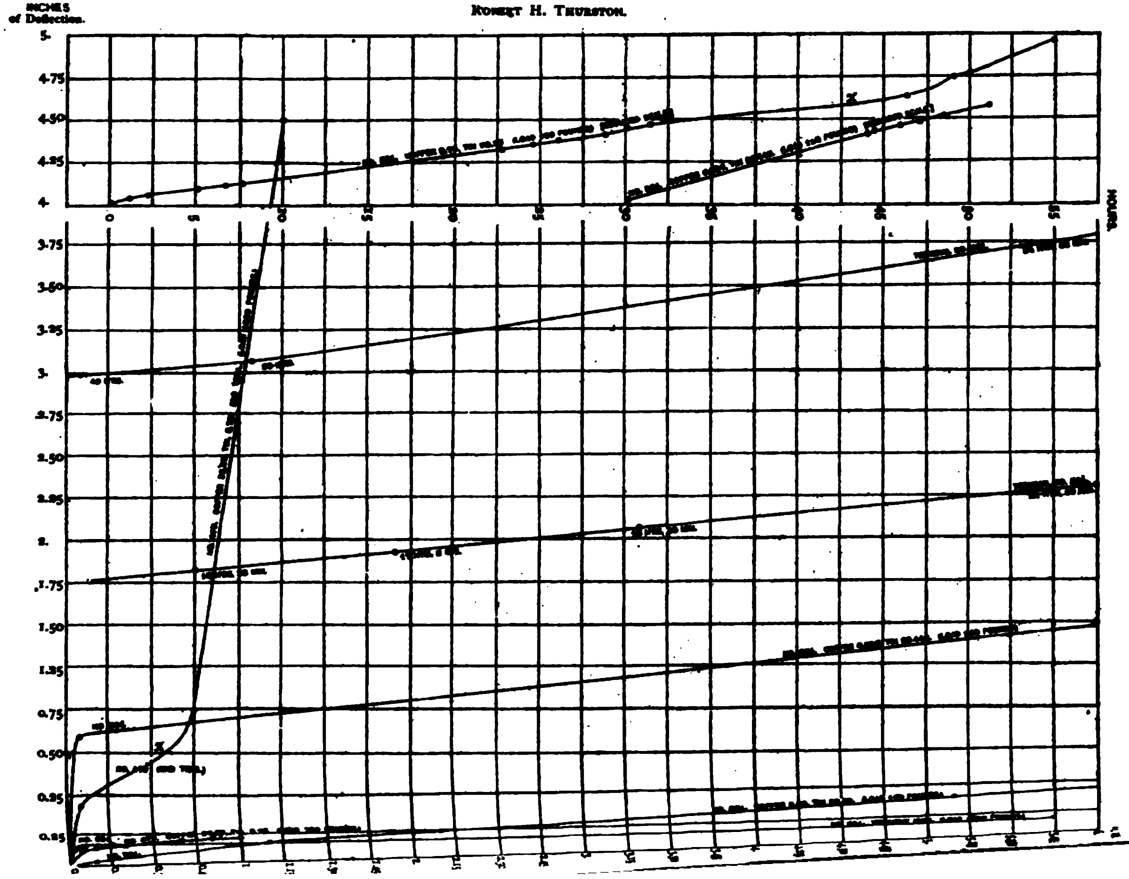


PLATE VIII.

INCREASE OF DEFLECTION WITH TIME IN TRANSVERSE TESTS OF BARS OF METAL.

RATE OF SET OF BARS, 1 INCH SQUARE 22 INCHES, BETWEEN SUPPORTS.

ROBERT H. THURSTON.



to be determined. The most probable and most satisfactory conclusion which seems likely to be finally reached is, perhaps, that the "iron class" of metals are capable of carrying indefinitely any load which they have once borne, and that, in some manner—by the relief of internal strain, as suggested by the writer,* or by some other process—their rest under a load renders them, as time goes on, more and more safe under that load.

RECORD OF EXPERIMENTS WITH DEAD LOADS TO DETERMINE THE INCREASE OF DEFLECTION WITH TIME, OR RATE OF SET.

Bars, 1 inch square; 22 inches between supports. Load applied at the middle.

No. 651.—WROUGHT IRON.

Load, 1,600 *pounds*.

Time.	Deflection.	Increase.	
		Difference.	Total.
Minutes.	*Inches.*	*Inches.*	*Inches.*
0	0.4890	....	....
1	0.5937	0.1047	0.1047
2	0.6197	0.0260	0.1307
3	0.6322	0.0125	0.1432
4	0.6410	0.0088	0.1520
5	0.6473	0.0063	0.1583
6	0.6504	0.0031	0.1614
16	0.6598	0.0094	0.1708
344	0.6598	0.0000	0.1708

Maximum load, 2,589 pounds; maximum deflection, 4.67 inches.

No. 504.—0.557 PARTS COPPER, 99.433 PARTS TIN.

Load, 110 *pounds*.

Time.	Deflection.	Increase.	
		Difference.	Total.
0	0.323	....	....
5	0.406	0.083	0.083
345	1.945	1.539	1.622
365	2.005	0.059	1.681
395	2.138	0.134	1.815
1,025	2.248	0.110	1.925
1,110	2.378	0.130	2.055
1,270	2.626	0.248	2.303

Maximum load, 130 pounds; maximum deflection, 3.11 inches.

No. 479.—96.27 PARTS COPPER, 3.73 PARTS TIN.

Load, 700 *pounds*.

Time.	Deflection.	Increase.	
		Difference.	Total.
0	0.441	....	....
5	0.559	0.118	0.118
10	0.583	0.024	0.142
20	0.601	0.018	0.160

Time.	Deflection.	Increase.	
		Difference.	Total.
Minutes.	*Inches.*	*Inches.*	*Inches.*
30	0.618	0.017	0.177
40	0.630	0.012	0.189
50	0.642	0.012	0.201
60	0.650	0.008	0.209
Set.	0.524	....	....

Second trial.—Load 1,000 *pounds*.

Time.	Deflection.	Increase.	
		Difference.	Total.
0	3.118	....	....
5	3.540	0.422	0.522
15	3.660	0.120	0.542
45	4.102	0.442	0.984
75	7.634	3.522	4.506

Bar broke under 1,000 pounds.

No. 501.—9.7 PARTS COPPER, 90.3 PARTS TIN.

Load, 160 *pounds*.

Time.	Deflection.	Increase.	
		Difference.	Total.
0	1.294	....	....
10	1.319	0.025	0.025
70	1.463	0.144	0.169
130	1.530	0.067	0.236
310	1.691	0.161	0.397
400	1.766	0.075	0.472
460	1.811	0.045	0.517
1,360	2.534	0.723	1.240
1,475	2.697	0.163	1.403
1,565	2.782	0.085	1.488
1,730	2.938	0.156	1.644
1,880	3.136	0.198	1.842
2,780	3.798	0.662	2.504
2,940	4.274	0.476	2.980
3,000	4.349	0.075	3.055
3,295	5.097	0.748	3.803

Bar left under strain at night and found broken in the morning.

The law of deflection and of rate of set, as illustrated graphically by the strain-diagrams given in this and in the preceding paper, is expressed for the lighter loads by equation of the form

$$Y=AT-BT^3$$

in which Y is the deflection or the set, both quantities varying together in this case, and T is the time; A and B being constant coëfficient to be determined for special cases.

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* Wire makers have learned that newly-made wire is considerably weaker than similar wire which has been so long made as to afford time for relief, by flow, of the internal straining introduced by the process of drawing.

For heavy loads, after the first sudden deflection and set, the equation is seen to be

$$Y = AT$$

in which for iron, $A = \frac{1}{Y}$ and for the tin-class A is a constant multiplier up to a limit x, Nos. 501, 479, at which it varies as some new function of the time.

The values of constants for the various metals remain to be determined. The question whether this change in the value of the modulus of rupture, as exhibited in the preceding section, and of the value of the quantity representing in the usual formula the amount of deflection, is due to a change in the modulus of elasticity, to simple flow, or to a variation of cohesive force, remains to be considered.

AMERICAN SOCIETY OF CIVIL ENGINEERS.

[Incorporated 1852.]

DISCUSSION AT THE SEVENTH ANNUAL CONVENTION.*

FLEXURE OF BEAMS.

Mr. **Robert H. Thurston**—Referring to "Resistances of beams to flexure":—†

1°. I agree fully with General Barnard in considering the formula of Navier, and those in common use as based upon them, as well as the arguments of Decomble sustaining the former, as not well supported by the results of experiment, except in a few special cases.

2°. The ordinary theory, and its resulting equations, in which the resistances of particles to compression and to extension are proportional to their distance from the neutral surface, are apparently sufficiently correct up to that limit of flexure at which the exterior sets of particles on the one side or on the other are forced beyond the elastic limit.

3°. With absolutely non-ductile materials, or materials destitute of viscosity, fracture occurs at this point. But, with ordinary materials, and notably with good iron, low steel, and all of the useful metals and alloys in common employ, rupture does not then take place.

4°. The exterior portions of the mass are compressed on the one side, offering more and more resistance nearly, if not quite, up to the point of actual breaking, which breaking may only occur long after passing the elastic limit. On the other side, the similar sets of particles are drawn apart, passing the elastic limit for tension, and then resisting the stress with approximately constant force, "flow" occurring until that limit of flow is reached, and rupture takes place.

5°. Fracture may occur under either of several sets of conditions.

A. The material may be absolutely brittle. (*a.*) In this case the elastic limit and the limit of rupture coincide for both simple tension and simple compression. The piece will break with a snap when, under flexure, either limit is reached. (*b.*) Or, it may happen that the limit is reached simultaneously on both sides.

B. The material may be slightly viscous. (*a.*) The flexure of the piece will produce compression or extension, or both, beyond the elastic limit before rupture, giving three sets of conditions to be expressed by the formula. (*b.*) The increase of resistance after passing the elastic limit will not be similar for both forms of resistance, and each substance will probably be found characteristically distinguishable from every other. (*c.*) It would appear from experiments already familiar, that the resistance to compression will frequently increase in a very high ratio as compared with that to extension, thus swinging the neutral surface toward the compressed side, and probably sometimes approximately to the limiting surface, with very hard and friable substances, thus bringing about something like a correspondence with "Galileo's theory." This, I presume, does not often happen.

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* Referring to Record of Experiments showing the character and position of Neutral Axes, as shown by polarized light, L. Nickerson, vol. iii, page 31; and to Resistance of Beams to Flexure, J. G. Barnard, vol. iii, page 123.

† Vol. iii, page 123.

C. The material may be very ductile or viscous.* (*a.*) In this case the phenomena of flexure and rupture will be as last described, but of exaggerated extent and importance. (*b.*) The resistances to extension and to compression as developed in this case will be approximately, or accurately, those observed in experiments producing rupture by direct tension and by direct compression. The neutral surface will be determined in position by the ratio of these ultimate resistances.

6°. Proposition 1, of Decomble, as rendered by General Barnard,† therefore, may or may not be true for any individual case, and it cannot be true for all materials. Proposition 2 is, I think, probably correct, it being understood that the effect of "flow" in producing modification of the coefficients of elasticity and of rupture is comprehended. Proposition 3 is, I should say, certainly incorrect for ductile substances.

Decomble is, therefore, in error in claiming that Navier's theories, narrow and inflexible as are their conditions, explain "all phenomena" of flexure and rupture, or that it can always give us correct moduli of rupture, or that it is in "complete harmony" with any but a narrow range of practice.

7°. The statement that "any load, however small," is "capable of producing rupture, providing that the trial is sufficiently prolonged," I have long since shown, by experiment (which has been published in this country and in Europe),‡ to be quite the reverse of the truth in the case of iron, steel, &c. The fact, as shown by the *fac-simile* strain-diagrams illustrating these papers, being that *static stress, less than that producing rupture, but greater than that corresponding with the elastic limit, produces actual increase of resisting power.* This fact has since been proven by other investigators and by quite independent methods of research.

8°. I have also shown in those experimental investigations that the converse fact exists, that *distortion, rapidly produced, causes an actual decrease of resisting power.* Strain-diagrams were given illustrating this fact very strikingly.

9° This variation of resistance with variation of the method of rupture introduces another element of uncertainty into "Navier's theory," as well as into all formulas yet constructed. This element must remain until experiment has indicated a measure of it and the form of the function expressing its law, and thus enable us to construct a correct formula.

10°. Referring to the remarks of General Barnard which follow the paper under discussion,§ we may find in the phenomena just considered a reason for the fact, remarked by him, that "beams fractured by shot did not resist anything like so much" as those broken under the slow and steady action of the hydraulic press.

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* It is to be remembered that viscosity and high cohesive force may coexist, as shown by Prof. Henry and Mon. Tresca.

† Vol. iii, page 123.

‡ Transactions, vol. ii, page 239; vol. iii, page 12, &c.; Journal of the Franklin Institute, 1874; Van Nostrand's Engineering Magazine, 1874; London Engineering, 1873; Practical Mechanics' Magazine, 1874; *Dingler's Polytechnisches Journal*, 1875.

§ Vol. iii, page 127.

11°. The assumption that resistances vary each way from the neutral surface proportionally with their distance from that surface is, when coupled with a rejected hypothesis of Navier, nevertheless, not far from the truth in special cases, as may be shown by proper mathematical treatment and comparison with results obtained experimentally.

12°. Mr. William Kent made this comparison for cast and wrought iron and for ash. The results of analysis and of experiment give the following values of the R in the ordinary formula:*

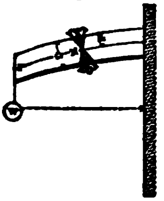
$$M=\frac{1}{6}\ R\ B\ D^2 \ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

for a beam fixed at one end, loaded at the other:

	Cast iron.	Wrought iron.	Ash.
R (theoretical)	32, 280	60, 000	12, 120
R (experimental)	35, 000	60, 000	12, 000

13°. This remarkable approximation is thus derived: Suppose a fixed beam, Fig. 5, with loaded extremity, the force P being a measure of the weight W, and the beam having a depth D, a breadth unity, and a neutral surface situated at a distance Y from the superior surface of the beam. Representing the resistances graphically by the triangles T N, C N; their measures in tension and compression are respectively $\frac{1}{2}$ T N, $\frac{1}{2}$ C N, and their moments are $\frac{1}{2}$ T N $\times\frac{2}{3}Y=\frac{2}{3}Y^2$, and $\frac{1}{2}$ C N$\times\frac{2}{3}(D-Y)=\frac{1}{3}C(D-Y)^2$. An early hypothesis of Navier, which seems to have been entirely abandoned by him subsequently, and which has not been accepted by subsequent writers on the subject, makes these moments equal. Assuming this to be correct,

Fig. 5.



$$T\ Y^2=C\ (D-Y)^2 \ldots\ldots\ldots\ldots\ldots\ldots(2)$$

$$\text{and } \frac{C}{T}=\frac{Y^2}{(D-Y)^2} \ldots\ldots\ldots\ldots\ldots\ldots(3)$$

and, from this expression, we may find the position of the neutral surface, as determined by the assumed conditions. Then letting B=the breadth of the beam,

$$W\ L=\frac{1}{3}\ B\ [T\ Y^2+C\ (D-Y)^2]=\frac{1}{6}\ R\ B\ D^2 \ldots\ldots\ldots(4)$$

in which latter expression R is the modulus of rupture, and its value can be found when C and T are known. It will always be of a value intermediate between T and C.

14°. The following are the data and results for the three cases taken; the results are well worthy of examination and record:

	T	C	B	D	L	Y	D—Y	W L	R
Cast iron	16, 000	96, 000	1	1	1	0. 71	0. 29	5, 380	32, 280
Wrought iron	60, 000	60, 000	1	1	1	0. 5	0. 5	10, 000	60, 000
Ash timber	17, 200	9, 000	1	1	1	0. 42	0. 58	2, 020	12, 120

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* Wood on Resistance of Materials.

15°. The common theory of rupture, as it is defined by Professor Wood, is confessedly far from correct, and, as shown at the beginning of these remarks, the neutral surface must vary in position, and cannot invariably pass through the center of gravity of section. It would seem that such coincidence of position, when occurring at all, is simply a matter of incidental concurrence of conditions. I therefore consider the criticism of General Barnard to be just in this point.

16°. The accurate mathematical expression of the phenomena of flexure and rupture, as already remarked, must be vastly more comprehensive and flexible and more facile of application than any yet proposed. As I have shown, it is not sufficient that both R_1 and R_2—*i. e.*, both T and C—appear in the formulas, as proposed by Decomble. The real value of these quantities, as there appearing, must vary as some function of distance from the neutral line, while the position of the neutral line must itself vary with both the value of T and C in different cases, and with their change of value in the same beam, as flexure progresses and after rupture commences. These variable functions must all be taken into account and comprised in the general expression for the moment resisting fracture.

The characters of these functions, however, are unfortunately not yet ascertained, and it is only after experiments in which the moment of resistance is accurately measured during every stage of fracture, and so completely that the strain-diagram of the experiments can be graphically given, or its equation constructed, that we can obtain their values. This has, as yet, been done in but few cases, as in some experiments of Hodgkinson, in the work of Styffe, and in experiments made by Rodman.

17°. It does not necessarily follow that the formulas finally resulting must be either complex or inconvenient of application. Simple expressions will, at least, be found for special cases of simple character, which will serve every purpose of the engineer.

18°. It is also true, as remarked by Professor Wood, and as known by every engineer, that the phenomena of flexure within admissible limits are much less complex and much less difficult of manipulation than those of rupture, or than those resulting in serious permanent distortion. Hence, it is true that ordinary engineering practice is not placed at such a serious disadvantage as these defects of the theory of strain might seem to indicate.

19°. In common with every member of the profession, I am called upon to admit the great services rendered us by Navier in the splendid work done by him at *l'Ecole des Ponts et Chaussées*, in establishing a theory of engineering, as well as in working up a theory of rupture, and I desire to acknowledge those services, while declining to admit absolute accuracy in his theories. They were constructed at a time when science was apparently divorced from the practice of engineering, and when his services in securing a genuine union were most invaluable. He must always be regarded as one of the great leaders of our profession.

I would unite with General Barnard in his remarks, relative to the attempt of Navier's pupil, Decomble, to retain the theory while modifying the formulas of Navier: "If by discarding a coefficient founded upon an imaginary coefficient of elasticity, and the introduction of distinct and independent factors, symbolic of resistance to rupture by compression and extension, it is shown that the Navier formula can be made reliable, an important service has been rendered to engineering science."*

I would myself add that the discovery and the mathematical expres-

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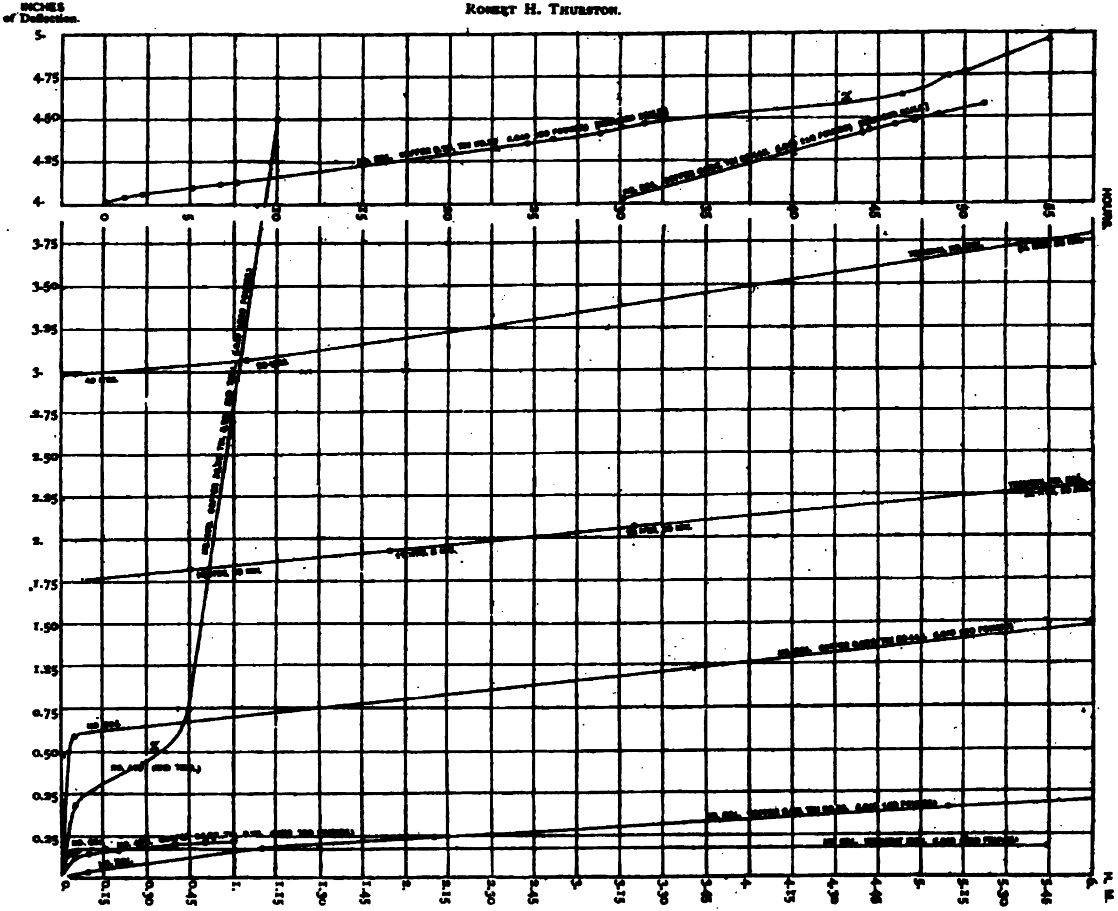
*Vol. iii, page 126.

Plate VIII.

INCREASE OF DEFLECTION WITH TIME IN TRANSVERSE TESTS OF BARS OF METAL.

RATE OF SET OF BARS, 1 INCH SQUARE 22 INCHES, BETWEEN SUPPORTS.

Robert H. Thurston.



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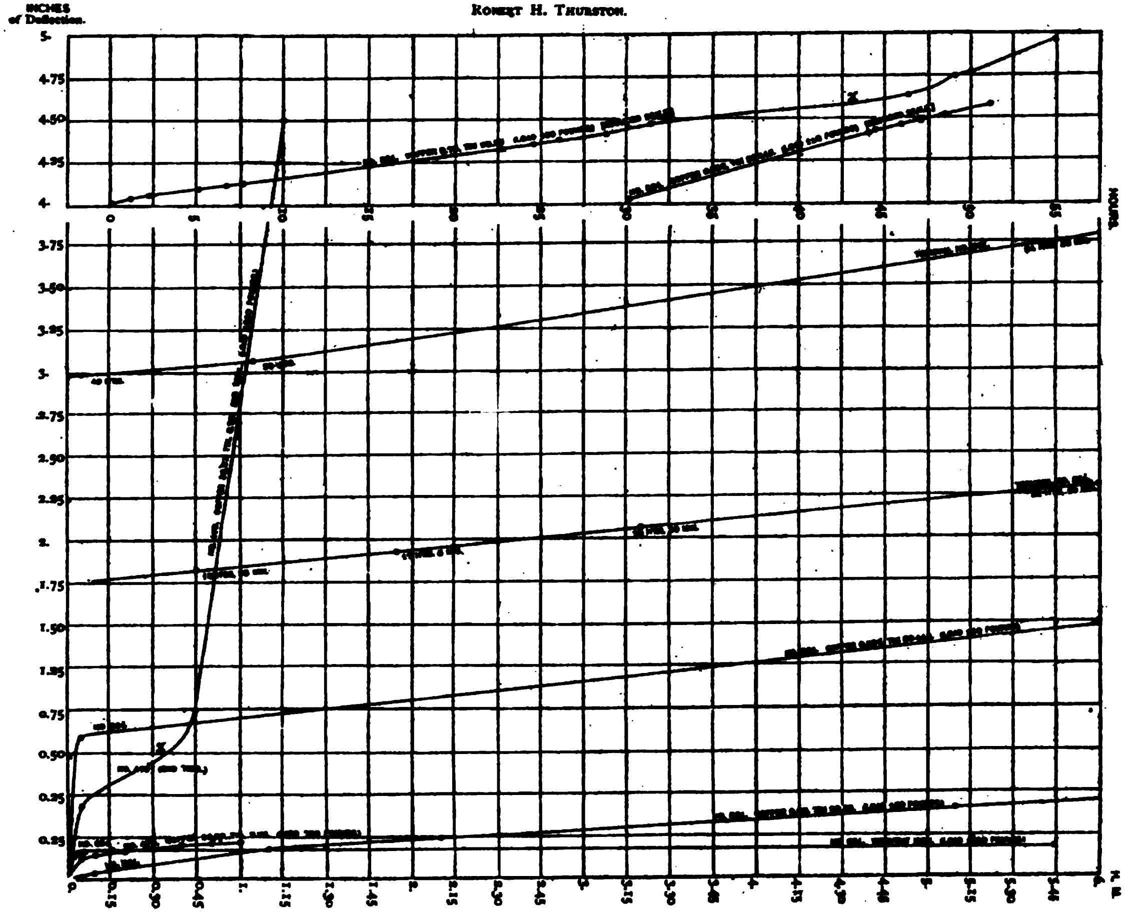

feature of chemical combination, does not take place to any great extent. The most unquestionable compounds of metals are still metallic in their general physical characters, and there is no such transmutation of the individuality of their constituents as takes place in the combination of a metal with oxygen, or sulphur, or chlorine, &c. The alteration of characters in alloys is generally limited to the color, degree of hardness, tenacity, &c.

Messrs. Calvert and Johnson,* about the year 1860, made a long series of experiments on alloys and amalgams made with pure metals, with the hope of throwing some light upon the subject, and of solving the question "Are alloys mixtures or compounds?" They believe that they have succeeded in ascertaining: First, the influence which each additional equivalent quantity of a metal exerts on another; secondly, the alloys which are compounds and those which are simply mixtures, for compounds have special and characteristic properties, while mixtures participate in the properties of the bodies composing them. They hold that the bronze alloys are definite compounds; for each alloy has a special value of conductivity of heat, and also its own specific gravity, and its own rate of expansion or contraction; while, on the contrary, the alloys of tin and zinc are mixtures; for they conduct heat, have a specific gravity and expand according to theory, or according to the proportions of tin and zinc which compose each alloy. Calvert and Johnson's conclusions are chiefly based upon their experiments on the heat conductivity of the alloys. Later experiments, made by Matthiessen,† on the conducting power for electricity, led him to different conclusions. He experimented on upwards of 250 alloys, all made of purified metals. The results of his investigations are published in a valuable paper, "On the Chemical Nature of Alloys," from which we transcribe the following classification of the solid alloys, composed of two metals, according to their chemical nature. The reasons for this classification are given in full in the above-named paper, but we must omit them here for want of space.

1. *Solidified solutions of one metal in another :*

The lead-tin, cadmium-tin, zinc-tin, lead-cadmium, and zinc-cadmium alloys.

2. *Solidified solutions of one metal in the allotropic modification of another :*

The lean-bismuth, tin-bismuth, tin-copper, zinc-copper, lead-silver, and tin-silver alloys.

3. *Solidified solutions of allotropic modifications of the metals in each other :*

The bismuth-gold, bismuth-silver, palladium-silver, platinum-silver, gold-copper, and gold-silver alloys.

4. *Chemical combinations :*

The alloys whose composition is represented by Sn_5 Au, Sn_2 Au and Au_2 Sn.

5. *Solidified solutions of chemical combinations in one another :*

The alloys whose composition lies between Sn_5 Au and Sn_2 Au, and Sn_2 Au and Au_2 Sn.

6. *Mechanical mixtures of solidified solutions of one metal in another :*

The alloys of lead and zinc, when the mixture contains more than 1.2 per cent. lead or 1.6 per cent. zinc.

7. *Mechanical mixtures of solidified solutions of one metal in the allotropic modification of the other :*

The alloys of zinc and bismuth, when the mixture contains more than 14 per cent. zinc or 2.4 per cent. bismuth.

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* See list of Calvert and Johnson's papers in the appendix.

† British Assoc. Reports, 1863, pp. 37–48.

8. *Mechanical mixtures of solidified solutions of the allotropic modifications of the two metals in one another:*

Most of the silver-copper alloys.

Matthiessen, however, does not claim that the above classification is not liable to exception. He was obliged to assume that some of the metals undergo a change, or are converted into an allotropic modification in the presence of another metal, in order to explain some of the phenomena which he observed, but he admits that until the allotropic modifications have been isolated, the assumption must remain an hypothesis.

To conclude, we can only say that the question is still unsettled. From the marked peculiarities of properties observed in a few of the alloys, we are led to pronounce them chemical compounds. Some others, we must admit, are simple mixtures, or rather, solidified solutions. But in regard to the large majority we are still in doubt. Further experiments may throw more light on the subject, but it is probable that with the larger number of alloys it will be found impossible to discover their exact chemical nature.

SPECIFIC GRAVITY.

The specific gravity of an alloy is rarely the mean between the densities of each of its constituents. It is sometimes greater and sometimes less, indicating, in the former case an approximation, and in the latter a separation of the particles from each other in the process of alloying. This subject has been studied by several writers, and their published results agree quite closely in regard to some of the alloys, but differ in regard to others. These differences may be accounted for by the differences in the apparatus used by the experimenters, by the fact that some determinations have been corrected for temperature and pressure of the atmosphere while others were not, but principally from the fact that several of the alloys are liable to be very deficient in homogeneity, and that the density of the same alloy will vary according to the conditions under which it is formed, as being cast too cold or too hot, cast in iron or in sand molds, &c. A bar cast in a vertical position is apt to have a greater specific gravity at the bottom of the bar than at the top. Repeated fusion of an alloy also causes changes in its density.

It is common among authorities who publish determinations of specific gravities of the alloys, to give the calculated as well as the observed specific gravity. The calculated specific gravity is that which the alloy would have if there were neither expansion nor condensation of the metals during the act of combination. Some writers have made a mistake in finding the calculated specific gravity by assuming it to be the arithmetical mean between the numbers denoting the two specific gravities, or, in other words, multiplying the percentage weight of each constituent by its specific gravity, adding the results and dividing by 100. The specific gravities should be calculated from the volumes and not from the weights. Dr. Ure* gives the correct rule as follows: Multiply the sum of the weights into the products of the two specific gravity numbers for a numerator, and multiply each specific gravity number into the weight of the other body and add the products for a denominator. The quotient obtained by dividing the said numerator by the denominator is the truly computed mean specific gravity of the alloy. Expressed in algebraic language, the rule is—

$$M = \frac{(W + w)\,P\,p}{P\,w + p\,W}, \tag{1}$$

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* Ure's Dictionary, vol. 1, p. 49.

where M is the mean specific gravity of the alloy, W and w the weights, and P and p the specific gravities of the constituent metals. Calvert and Johnson* seem to have fallen into the error just mentioned, and the expansion and condensation of different alloys as given by them is not strictly correct. Professor Bolley has also committed the same, as shown by Matthiessen.†

The observed, or real, specific gravities of the alloys, however, published by these writers, are not affected by the error named, and they are, no doubt, worthy of acceptance.

The valuable compilation of the "Constants of Nature,"‡ published by the Smithsonian Institution, contains a full table of specific gravities of the alloys, with the names of about twenty-five authorities. Of these, the principal are Mallet,§ Calvert and Johnson,‖ Matthiessen,¶ and Riche.**

The following table of the alloys whose density is greater or less than the mean of their constituents, is given by several writers:

Alloys, the density of which is greater than the mean of their constituents.	Alloys, the density of which is less than the mean of their constituents.
Gold and zinc.	Gold and silver.
Gold and tin.	Gold and iron.
Gold and bismuth.	Gold and lead.
Gold and antimony.	Gold and copper.
Gold and cobalt.	Gold and iridium.
Silver and zinc.	Gold and nickel.
Silver and tin.	Silver and copper.
Silver and bismuth.	Iron and bismuth.
Silver and antimony.	Iron and antimony.
Copper and zinc.	Iron and lead.
Copper and tin.	Tin and lead.
Copper and palladium.	Tin and lead.
Copper and bismuth.	Tin and palladium.
Lead and antimony.	Nickel and arsenic.
Platinum and molybdenum.	Zinc and antimony.
Palladium and bismuth.	

The above table is probably inaccurate in many respects. Calvert and Johnson agree with Matthiessen in giving the density of the alloys of lead and antimony as less than the mean of the constituents, and Matthiessen shows the alloys of lead and gold to have a greater density than the mean of their constituents. Some alloys of tin and gold and of bismuth and silver are shown by Matthiessen to have a greater, and some a less, density than the mean of their constituents, and the same is true of the alloys of some other metals.

FUSIBILITY.

A remarkable property of many of the alloys is their great fusibility. In nearly all cases the fusing point of an alloy is lower than the mean of its constituent metals, and in some instances, as in the so-called fusible alloys, it is lower than that of either. The cause of this fact has not been definitely ascertained. Some regard it as a proof that the alloy is a distinct chemical compound, but most authorities differ from this view. Matthiessen* supposes that chemical combinations may exist in the fused mass, which suffer decomposition on cooling or solidifying. He says that the low fusing points admit of explanation by assuming that chemical attraction between the two metals comes into play as soon as the temperature rises, and the moment the smallest portions melt, then the actual chemical compound is formed which fuses at the lowest temperature, and then acts as a solvent for the particles next to it, and so promotes the combination of the metals where this can take place.

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* Phil. Mag., vol. 18, 1859, pp. 354–359.

† Jour. Chem. Soc., vol. 15, 1862, pp. 30, 106.

‡ Constants of Nature, published by the Smithsonian Institution, Washington, D. C., 1873.

§ Phil. Mag., vol. 21, 1842, pp. 66–68.

‖ Phil. Mag., vol. 18, 1859, pp. 354–359.

¶ Phil. Trans., 1860, pp. 177–184.

** *Comptes Rendus*, vol. 55, 1862, pp. 143–147.

In another place† Matthiessen remarks that all mixtures have a lower fusing point than the mean of the substances forming the mixture; for instance, salt-water solidifies below zero, and a mixture of the chlorides of sodium and potassium fuses at a lower point than the mean of the fusing points of the components.

This fact, he believes, admits of explanation as follows:

> It is generally admitted that matter in the solid state exhibits an excess of attraction over repulsion, while in the liquid state these forces are balanced, and in the gaseous state repulsion predominates over attraction. Let us assume that similar particles of matter attract each other more powerfully than dissimilar ones. It will then follow that the attraction subsisting between the particles of a mixture will be sooner overcome by repulsion than in the case of a homogeneous body; hence mixtures should fuse more readily than their constituents.

Some alloys have been observed to fuse at one point and solidify at a lower one; for example, the tin-lead alloys, which all solidify at 181° C., but the fusing point of which varies with the different proportions of the component metals from 181° C. to 292° C.

Concerning these alloys, Pillichody‡ remarks as follows:

> When the points of solidification are observed by immersing the thermometer in the melted alloy, it usually exhibits, during the passage of the mass from the liquid to the solid state, two stationary points. This effect is due to the separation of one or other of the component metals, while an alloy of constant composition still remains liquid. This alloy corresponds to the composition $Sn_3 Pb$. An alloy richer in lead would first deposit lead, and an alloy containing a larger proportion of tin would first deposit tin—the alloy $Sn_3 Pb$ remaining liquid for a longer or shorter time, and ultimately solidifying at 181° C. This temperature therefore corresponds to the lowest melting point that can be exhibited by an alloy of tin and lead, a larger proportion of either metal causing the melting point to rise.

With the exception of the alloys of tin and lead, and the fusible alloys, the fusing points of but few of the alloys have been determined. An accurate pyrometer for temperatures above red heat is greatly needed for this purpose. The "Constants of Nature," while it has the specific gravities of several hundred alloys, gives the melting points of only six, exclusive of the fusible alloys and those of lead and tin. Mallet§ gives the relative fusibility of the several alloys of copper and tin and copper and zinc, and shows that their fusibility increases regularly as the proportion of copper in the alloy diminishes.

Some alloys in passing from the liquid to the solid state do not change at once, but remain for some time in a pasty condition. Their temperature of solidification, therefore, cannot be distinctly recognized. This is the case with an alloy of the composition $Bi_2 Pb Sn_2$, which is fusible in boiling water, but which remains in a pasty condition through an interval of several degrees of temperature, so that it can be handled like a plaster.

M. Person‖ made experiments upon the alloys $Bi_3 Pb_2 Sn_2$ (D'Arcet's alloy, fusible at 96° C.), $Bi_2 Pb Sn_2$ (fusible in boiling water), and $Bi Pb Sn_2$ (fusible at 145° C.), and formed the conclusion that it is possible to assign in advance the heat necessary to fuse an alloy, if that required to fuse each of its component metals is known. He gives the formula $(160 + t) \vartheta = l$, in which t is the temperature at which fusion is effected; for example, 332° C. for lead if melted alone, but only 96° C. if melted in D'Arcet's fusible alloy; l is the expenditure of heat necessary to produce the fusion; that is, a certain number of *calories* (1 *calorie* = 3.96 British thermal units) variable with t; ϑ is the difference of the specific heats of the liquid and solid. If t and l are known, ϑ can be found. In the case of tin, $t = 235$, $l = 14.3$, from which $\vartheta = 0.0362$. Having this value of ϑ, it is easy to calculate the heat necessary to melt tin at any temperature whatever, for instance at 96° C., for which we find 9.3 *cal.* Making the same calculation for bismuth and for lead we find 7.382 and 2.7 *cal.* It only remains to take these numbers in the proportion in which each metal exists in the alloy, which gives a little less than 6.3 *calories*, which differs from the number found by experiment (6 *cals.*) only 0.3 *cal.*

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* British Assoc. Reports, 1863, p. 42.
† Jour. Chem. Soc., vol. 5, 1867, p. 207.
‡ Jour. Chem. Soc., vol. 15, 1862, p. 30.
§ Phil. Mag., vol. 21, 1842, pp. 66–68.
‖ *Comptes Rendus*, vol. 25, 1847, pp. 444–446.

Nothing appears to have been written upon this branch of the subject since M. Person's paper was published, but it is probable that if the investigation was pursued further our knowledge of the causes of the remarkable fusibility of the alloys would be much increased.

M. Riche* has determined the melting points of certain alloys of tin and copper, by means of Becquerel's thermo-electric pyrometer. He obtained concordant results with the alloys $Sn Cu_3$ and $Sn Cu_4$, but with all other alloys the results differed widely among themselves.

W. C. Roberts,† chemist to the British mint, has published a series of determinations of the melting points of several alloys of silver and copper. The temperature was estimated by finding the amount of heat contained in a wrought-iron cylinder of known weight which was dropped into the melted alloy while in the furnace, and removed as soon as the mass showed signs of solidifying. The specific heats of the iron and of the alloy were the data used in the calculation. The alloy, composed of 630.29 parts of silver and 369.71 parts of copper, corresponding to the formula $Ag Cu$, showed the lowest fusing point, or 846.8° C.; that of pure copper being 1330° C., and that of pure silver 1040° C.

LIQUATION.

Many of the alloys exhibit the phenomena of liquation, or separation of the mass of melted metal in the act of solidification into two or more alloys of different composition. The resulting alloy or mixture of alloys is consequently deficient in homogeneity. The causes of this separation are as yet but imperfectly understood. Some observations seem to show that an alloy of constant composition and of a comparatively high fusing point solidifies first in crystals disseminated throughout the mass, while the remainder of the melted metal remains fluid for a longer time, and finally solidifies around and among these crystals. This fact would tend to prove that the first alloy solidified was a distinct chemical compound, but it has been shown that crystals of exactly the same appearance have been formed from two metals in a wide range of proportions.

The different circumstances under which the separated alloys may be formed, such as the heat of the metal when poured into the mold, and the fact of slow or of rapid cooling, are known to have some influence upon the amount of liquation, or the difference of composition of different parts of the same casting, but this influence is not exerted upon all alloys in the same direction, some alloys being affected in one way and some in another by the same manner of treatment. The bronze alloys, such as gun-metal, are said to have the liquation diminished by rapid cooling. When the mass is cooled slowly, bronze castings often show in the interior what are called spots of tin, but what are really spots of a white alloy of copper and tin, containing a larger percentage of tin than the average of the whole casting. When slowly cooled, also, the bottom of the casting is often found to contain a larger percentage of copper than the top. When cooled rapidly, however, as shown in the experiments of General Uchatius[*] in casting cannon in chilled molds, the liquation is reduced to a minimum, and the resulting alloy is more homogeneous.

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* *Ann. de Chim.*, vol. 30, 1873, p. 351.

† Proc. Roy. Soc., vol. 23, 1875, pp. 481–495.

Levol[†] made some experiments on the liquation of the alloys of silver and copper, and concluded that the only homogeneous alloy of these two metals was the one whose composition is 718.97 parts of silver and 281.07 parts of copper, corresponding to the formula $Ag_3\ Cu_2$, and that all the others are liable to more or less liquation. It has lately been shown, however, by Mr. W. C. Roberts,[‡] chemist to the British mint, that this alloy is only homogeneous when cooled rapidly. If the cooling is slowly effected, its homogeneity is disturbed, the external portions being slightly richer in silver than the center.

Mr. Roberts made several determinations of the liquation of other alloys of silver and copper, and found that the arrangement of an alloy is to a great extent dependent on the rate at which it is cooled, and that several alloys of silver and copper are under suitable conditions as homogeneous as Levol's alloy. The alloy of 925 parts silver and 75 parts copper was found to be nearly homogeneous when cooled very slowly, the composition of the corners and center of a cube 45 millimeters on a side showing a maximum difference of only 1.4 parts in 1,000, while the same when cooled rapidly showed a difference of 12.8 parts in 1,000.

Col. J. T. Smith[§] relates in reference to some experiments made by him on the alloy of silver and copper containing 91⅔ per cent. of silver, that the separation of the constituent parts of the alloy was not so much due to the rapidity or slowness with which the heat of the fluid metal was abstracted, as to the inequality affecting its removal from the different parts of the melted mass in the act of consolidation. Thus, if a crucible full of the melted alloy were lifted out of the furnace and placed on the floor to cool, the surface of the melted metal within it being well covered with a thick layer of hot ashes, the lower parts of the mass after it had become solid would be found to contain less silver in proportion than the upper surface.

If, on the other hand, the crucible were left to cool while imbedded in the furnace, the upper surface being exposed to the air, then the lower parts would, after solidification, be found finer than the upper surface.

Riche[‖] has made several experiments on the liquation of the alloys of copper and tin. He remarks that to manifest the property of liquation, it is necessary to agitate the crucible containing the melted alloy, at the moment of solidification, in order to separate the small crystals already formed. The results obtained on the last product, remaining liquid in a mass weighing 1,000 to 1,200 grammes, showed a remarkable liquation of all the alloys of copper and tin except those corresponding to the formulae Sn Cu_3 and Sn Cu_4.

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[*] Ordnance Notes No. XL, Washington, D. C., 1875.

[†] *Ann. de Chim.*, vol. 36, 1852, pp. 193–224.

[‡] Proc. Roy. Soc., vol. 23, 1875, pp. 481–495.

[§] Proc. Roy. Soc., vol. 23, 1875, pp. 433–435.

[‖] *Comptes Rendus*, vol. 67, 1868, pp. 1138–1140, and vol. 30, 1873, pp. 351–419.

Several other alloys exhibit like phenomena to an even greater extent than those above mentioned. Matthiessen and Von Bose experimented upon alloys of lead and zinc and bismuth and zinc, melting the metals together in various proportions, and found that one end of a bar would have an excess of one metal and the other end an excess of the other. Alloys of copper and lead containing an excess of lead show a liquation in a remarkable degrees, the excess of lead partly oozing out from the mass on cooling.

SPECIFIC HEAT.

The published determinations of the specific heat of the alloys are not numerous. This results not from any difficulty of making the observations, but probably because they have not been considered of such practical importance as those of other properties, and partly, also, because M. Regnault's* determinations, made in 1841, and his deductions therefrom, are accepted as final.

M. Regnault determined the specific heat of two classes of alloys: first, those which at 100° C. are considerably removed from their fusing points; and, secondly, those which fuse at or near 100° C. The specific heats of the first series were remarkably near to that calculated from the specific heats of the component metals, so that he announced the following law:

"*The specific heat of the alloys, at temperatures considerably removed from their fusing point, is exactly the mean of the specific heats of the metals which compose them.*"

The mean specific heat of the component metals is that obtained by multiplying the specific heat of each metal by the percentage amount of the metal contained in the alloy and dividing the sum of the products for each alloy by 100.

A curious fact discovered in regard to these alloys is also that the product of the specific heat of each alloy by its atomic weight is sensibly constant, varying in the whole series only from 40.76 to 42.05.

The second series of alloys, or those which fuse at a temperature at or near 100° C., show a wide divergence from the above law, the specific heats of all of these being much higher than that calculated from their constituents. The product of the specific heats by the atomic weights varied also, from 45.83 to 72.97.

Matthiessen† describes a simple arrangement of the differential thermometer for the purpose of showing that the specific heat of an alloy is the same as the mean of those of its components.

EXPANSION BY HEAT.

The expansion of the alloys by heat has been examined by Messrs. Calvert and Lowe,‡ with a view to learn whether their expansion followed the law of the proportions of their components. Four series of alloys were examined, namely, those of zinc and tin, lead and antimony, zinc and copper, and copper and tin. In each case the expansion was less than that deduced by calculation from their equivalents.

**Ann. de Chim.*, vol. 1, 1841, pp. 129–207.
†Jour. Chem. Soc., vol. 5, 1867, p. 205.
‡Chem. News, vol. 3, 1861, p. 315.

In alloys of copper with tin, it was found that where only a small quantity of tin entered into the composition of a bar, the expansion fell considerably below that of pure copper, although the tin added has a much higher rate of expansion than copper.

From experiments made by Messrs. Calvert and Lowe upon the expansion of chemically pure metals, they conclude that a very small proportion of impurity has a marked influence upon the expansion. Their results differed largely from those of other experimenters who used only the commercial metals; but when they, too, used commercial metals, the results agree.

The alloys upon which they experimented were also formed from pure metals, and on account of the difficulty of procuring these in sufficient quantity, the bars experimented on were very small, being only 60 millimeters, or less than $2\frac{1}{2}$ inches long. The apparatus used, however, as described at length in the "Chemical News," was so sensitive, that an expansion of $\frac{1}{50000}$ of an inch could readily be observed.

If experiments were made upon alloys formed from the ordinary commercial metals, it would probably be found that their rate of expansion would differ considerably from that of alloys formed from pure metals.

The molecular condition of a metal was observed to have an important influence on the rate of expansion. The same will no doubt be found true in the case of alloys.

Matthiessen* states that the expansion due to heat of the metals takes part in that of their alloys approximately in the ratio of their relative volumes. He gives a table of the expansion of several alloys which tends to confirm his statement.

CONDUCTIVITY FOR HEAT.

The power of the alloys to conduct heat has been examined with great care by several experimenters. The published results are not always concordant, but the differences may be partially accounted for by the various kinds of apparatus used, and the great influence which small impurities and changes in molecular condition and crystalline form exert upon conductivity.

The conducting power for heat in an alloy is found in some cases to be the mean of the conducting power of the component metals, and in others to apparently have no relation whatever to such mean. As examples of the first case may be cited the alloys of tin and zinc, and tin and lead; and of the second, the alloys of gold and silver and gold and copper. From this circumstance it has been expected that the heat-conducting power could be used as a means of determining whether an alloy is a chemical compound or a simple mixture. As before stated, however, the authorities differ widely on this point.

Messrs. Weidemann and Franz,† in 1853, made some experiments on the conducting power of the metals and of a few of the alloys, using a thermo-electroscope as an apparatus.

In 1858, Calvert and Johnson‡ made an extensive research on alloys formed from pure metals, using an apparatus of their own invention, by which the relative conducting power was shown by the rise in temperature in a given time of a given volume of water secured in a box at one end of the bar, while the other end of the bar was heated to 90° C. They claim that the method which they employed gave such consistent results, that they were able to determine the influence exercised on the conducting power of the metals by the addition of 1 or 2 per cent. of another metal, and also to appreciate the difference of conductivity of two alloys made of the same metals and only differing by a few per cent. in the relative proportions of the metals composing them. They found also that the conducting power of metals was different when they were rolled out into bars or cast, and that it was modified by molecular arrangement or position of the axes of crystallization, as was shown by the different conducting power of metals cast horizontally and vertically. Some curious results were observed in regard to alloys of gold and silver. Silver being the best conductor, its conductivity is rated as 1,000, and that of gold, the next, is 981; but gold alloyed with 1 per cent. of silver has a relative conductivity of only 840.

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* Jour. Chem. Soc., vol. 5, 1867, p. 206.

† *Pogg. Annalen*, vol. 89, 1853, pp. 497–531.

‡ Phil. Trans., 1858, pp. 349–368.

The conduction of heat by alloys, according to Calvert and Johnson, may be considered under three general heads:

1. *Alloys which conduct heat in ratio with the relative equivalents of the metals composing them.*

2. *Alloys in which there is an excess of equivalents of the worse conducting metal over the number of equivalents of the better conductor*, such as alloys composed of 1 Cu and 2 Sn, 1 Cu and 3 Sn, &c., and which present the curious and unexpected rule that *they conduct heat as if they did not contain a particle of the better conductor*, the conducting power of such alloys being the same as if the bar was entirely composed of the worse conducting metal. A not less remarkable fact is that the alloys of a series, such as those of 2 equivalents of bismuth and 1 of lead, 3 Bi and 1 Pb, 4 Bi and 1 Pb, all conduct heat alike, the various increasing quantities of lead exercising no influence on the conductivity.

The results obtained with this class of alloys are most important to engineers; for it will be seen in the case of alloys of brass and bronze that no increase is gained in the conductivity of an alloy by increasing the quantity of a good conductor; nay, in many cases it would be a decided loss, unless a sufficient quantity of the better conducting metal be employed to bring the alloy under the third head.

3. *Alloys composed of the same metals as the last class, but in which the number of equivalents of the better conducting metal is greater than the number of equivalents of the worse conductor;* for example, alloys composed of 1 Sn 2 Cu, 1 Sn 3 Cu, &c. In this case each alloy has its own arbitrary conducting power; the conductivity of such an alloy gradually increases and tends towards the conducting power of the better conductor.

In a later experiment upon the conductivity of mercury and the amalgams, Calvert and Johnson* discovered that they had made a great mistake in their first experiment in determining the conductivity of mercury, by disregarding the fact that convection of the liquid increased the apparent conductivity. In the first experiments they found the apparent relative conductivity to be 677, silver being 1,000; but in the later experiments they determined the real relative conductivity to be only 54, or less than that of any other metal. In regard to the fluid amalgams, they found in all cases that their conductivity was nearly the same as that of pure mercury.

Weidemann,† in 1859, published a paper in which he calls in question the accuracy of the results found by Calvert and Johnson, and criticises the apparatus they used and the small size of the bars upon which they experimented. He also gives the results of some experiments which he has made upon the conductivity of a few alloys.

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* Phil. Trans., 1859, pp. 831–835.

† *Pogg. Annalen*, vol. 108, 1859, pp. 393–406.

Matthiessen[*] describes a simple apparatus for showing the different conductivities of alloys. He also states that the conductivity for heat furnishes no evidence of whether an alloy is a chemical compound or a mixture.

CONDUCTIVITY FOR ELECTRICITY.

The conductivity for electricity, like the conductivity for heat, is one of the properties which in some alloys is the mean of that of the component metals, and in others seems to have no relation whatever to such mean.

There have been a large number of experiments made upon the electric conductivity of the alloys, but in this, as in the examination of other properties, with widely varying results. In the first place, the determinations of the conducting powers of the metals themselves are far from agreeing, as, for instance, the conductivity of copper, according to different experimenters, is given at numbers ranging from 66 to 100, pure silver being 100.

Again, Matthiessen[†] has shown that small traces of the metals, and especially of the metalloids, reduce the conductivity of copper to a great extent. He states, also, that there is no alloy of copper which conducts electricity better than pure copper,and that the fact of the wires experimented upon being annealed or hard drawn causes a marked difference in the values obtained, annealed wire being a better conductor than hard drawn; and, further, that temperature has likewise a marked influence, the metals losing in conducting power as the temperature increases.

In 1833, Professor Forbes[‡] publishedthe statement that the order of conducting powers of the metals for heat and for electricity is the same. He states, as a general conclusion, "that the arrangement of metallic conductors of heat does not differ more from that of those of electricity than either arrangement does alone under the hands of different observers."

Twenty years later, Weidemann and Franz[§] arrived at the same conclusion in regard to brass and German silver, and Weidemann[‖] in 1859 concluded the same in regard to alloys in general. Weidemann and Franz remarked that whatever the quality may be upon which calorific conduction depends, the close agreement of the figures renders it exceedingly probable that the same quality influences in a similar manner the transmission of electricity; for the divergence of the numbers expressing the conductivity for heat from those expressing the conductivity for electricity are not greater than the divergences of the latter alone, exhibited by the results of different observers.

The most extensive series of investigations upon the electric conductivity of alloys has been made by Matthiessen. His results are published in the following papers: "On the Electric Conducting Power of the Metals";[¶] "On the Electric Conducting Power of Alloys";[**] "On the Influence of Temperature on the Electric Conducting Power of Alloys";[††] "On theThermo-Electric Series";[‡‡] "On the Effect of the Presence of the

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[*] Jour. Chem. Soc., vol. 5, 1867, p. 213.

[†] Phil. Trans., 1860, pp. 85–92.

[‡] Phil. Mag., vol. 4, 1834, p. 27.

[§] *Pogg. Annalen*, vol. 89, 1853, pp. 497–531.

[‖] *Pogg. Annalen*, vol. 108, 1859, pp. 393–407.

[¶] Phil. Trans., 1858, pp. 383–387.

[**] Phil. Trans., 1860, pp. 161–176.

[††] Phil. Trans., 1864, pp. 167–200.

[‡‡] Phil. Trans., 1858, pp. 369–381.

Metals and Metalloids upon the Electric Conducting Power of Pure Copper";* "On the Chemical Nature of Alloys".†

It was chiefly from these researches that Matthiessen arrived at the conclusions in regard to the question whether alloys are chemical compounds or mixtures, which have already been given under the head of the chemical nature of alloys.

In regard to the conducting power for electricity of the alloys, Matthiessen divides the metals into two classes:

Class A.—Those metals which, when alloyed with one another, conduct electricity in the ratio of their relative volumes.

Class B.—Those metals which, when alloyed with one of the metals belonging to class A, or with one another, do *not* conduct electricity in the ratio of their relative volumes, but always in a lower degree than the mean of their volumes.

To Class A belong lead, tin, zinc, and cadmium. To class B belong bismuth, mercury, antimony, platinum, palladium, iron, aluminum, gold, copper, silver, and in all probability most of the other metals.

CRYSTALLIZATION.

The crystallization of alloys exhibits some curious phenomena. It was formerly supposed that if a distinct crystal of an alloy were found, it would have a definite chemical composition, and would show that the alloy was not a mixture, but a veritable chemical compound.

In 1854, however, Prof. J. P. Cooke ‡ published a paper on two crystalline compounds of zinc and antimony, which exhibited such properties as justified him in considering them definite chemical compounds. To distinguish them, he gave them the names of Stibiotrizincyle, with the formula $Sb\ Zn_3$, and Stibiobizincyle, with the formula $Sb\ Zn_2$. In the paper named, the crystalline form and other properties are fully described.

A short time afterward, it was found that well-defined crystals, like those described as $Sb\ Zn_3$, were obtained from the alloys containing between 43 and 60 per cent. of zinc; and even in alloys of a higher zinc percentage crystals of the same form were still seen, although they were no longer well defined. In the alloys containing between 20 and 33 per cent. of zinc, well-defined crystals, like those described as $Sb\ Zn_2$, were formed; and finally, there separated from the alloys containing between 33 and 42 per cent. of zinc, thin metallic plates, which evidently belonged to the same crystalline form.§

The same fact has been observed by Matthiessen and Von Bose ‖ in regard to the alloys of gold and tin, namely, that well-defined crystals are not limited to one definite proportion of the constituents of an alloy, but are common to all gold-tin alloys containing from 43 to 27.4 per cent. of gold. They also found in the case of these alloys that the crystals and the mother liquor were never of the same composition, the percentage of gold in the mother liquor being much below that in the crystals.

From experiments by F. H. Storer,¶ it appears that the alloys of copper and zinc yield crystals, sometimes exhibiting distinct octahedral faces, sometimes in confused aggregates of crystals, but all of octahedral character, and bearing a striking resemblance to the crystals of pure copper obtained by fusion. None of the crystals were found to contain a larger proportion of either metal than the remainder of the molten liquid from which they had separated. Storer concludes that all the alloys of copper and zinc crystallize in the regular system, and that they are not definite atomic compounds, but merely isomorphous mixtures of the two metals.

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*Phil. Trans., 1860, pp, 85–92.

† British Assoc. Reports, 1863, pp. 37–48.

‡ Am. Jour. Arts & Sci., vol. 18, 1854, pp. 229–237.

§ Am. Jour. Arts & Sci., vol. 20, 1855, pp. 222–238.

‖ Proc. Roy. Soc., 1860–'62, pp. 433–436.

¶ Memoirs of the American Academy, vol. 8, 1863, pp. 27–56.

Calvert and Johnson* have also noticed the crystallization of the alloys of copper and zinc, and state that it is probable that Cu_2 Zn, and Cu_3 Zn are definite compounds, as they are perfectly crystallized, and have also a special heat-conducting power of their own. They state that the most splendid of all the brass alloys is the alloy Cu Zn, which is of a beautiful gold color, and crystallizes in prisms often 3 centimeters long.

Slow cooling of an alloy is apt to favor the separate crystallization of one or more of its components, and thus render it brittle. Sometimes in casting an alloy in large masses, there will be a partial separation of the constituents, and crystals of different composition will be found at the top and bottom of the mass, those at the bottom usually containing the larger percentage of the metal which has the greater specific gravity. This phenomenon has already been noted under the head of liquation.

OXIDATION AND ACTION OF ACIDS.

But few experiments have been made to determine the rate of oxidation or corrosion of the alloys by atmospheric influences or by the action of acids. It is generally found that the action of the atmosphere is less on alloys than on their component metals. An instance of this is the ancient bronze statues and coins, some of the latter of which have their characters still legible, although they have been exposed to the effects of air and moisture for upward of twenty centuries.

The action of the atmosphere on an alloy heated to a high temperature is sometimes quite energetic, as is shown in the alloy of three parts lead and one of tin, which, when heated to redness, burns briskly to a red oxide. When two metals, as copper and tin, are combined, which oxidize at different temperatures, they may be separated by continued fusion with exposure to the air. Cupellation of the precious metals is a like phenomenon.

Mushet† found that unrefined copper resisted the action of muriatic acid better than pure copper. This he thought was due to the presence of tin in the unrefined copper, as he found that an alloy of copper containing about 3 per cent. of tin resisted the action of acid to still greater extent. The latter he recommends for the purpose of ship-sheathing.

Calvert and Johnson‡ have made several experiments to determine the action of nitric, hydrochloric, and sulphuric acids upon alloys of copper and zinc and copper and tin. Some of the results they obtained were entirely unexpected. Nitric acid of 1.14 specific gravity was found to dissolve the two metals in an alloy of zinc and copper in the exact proportion in which they exist in the alloy employed, while an acid of 1.08 specific gravity dissolved nearly the whole of the zinc and only a small quantity of the copper. Hydrochloric acid of 1.05 specific gravity was found to be completely inactive on all alloys of copper and zinc containing an excess of copper, and especially on the alloy containing equivalent proportions of each metal. Zinc was found to have an extraordinary preventive influence on the action of strong sulphuric acid on copper.

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*Phil. Trans., 1858, p. 367.

†Phil. Mag., vol. 6, 1835, pp. 444–447.

‡Phil. Mag., vol. 10, 1855, pp. 250, 251; also, Jour. Chem. Soc., vol. 19, 1866, pp. 434–454.

The alloys of copper and tin were all found to resist the action of nitric acid more than pure copper, but the preventive influence of tin presents the peculiarity that the action of the acid increases as the proportion of tin increases; thus the alloy $Cu\ Sn_5$ is attacked ten times more than the alloy Cu Sn. The alloys $Sn\ Cu_2$ and $Sn\ Cu_3$ were attacked by strong sulphuric acid with more violence than any other of the bronzes.

Three alloys, viz, Cu_{18}, Zn Sn, Cu_{10} Zn Sn, and $Cu_4\ Zn_3$, were found to be only slightly attacked by strong nitric or hydrochloric acids, and not at all by sulphuric acid. The resistance to the action of nitric acid is remarkable, as its action on each of the component metals is very violent.

A. Bauer* has recently published in the *Berichte der deutschen chemischen Gesellschaft* the result of some experiments on the action of hot sulphuric acid on several alloys of lead. These experiments show that the addition of a little antimony or copper renders the alloy more able to resist sulphuric acid, while bismuth has a decidedly injurious effect.

HARDNESS AND OTHER MECHANICAL PROPERTIES.

The mechanical properties of the alloys, such as hardness, malleability, ductility, resistance to strains of tension, compression, and torsion, elasticity, resilience, &c., are of the utmost importance to the engineer, but, at the same time, it is most difficult to find reliable information regarding them. But few experimenters of authority have investigated the subject, and their researches, although valuable as far as they go, are too limited in extent to allow of a complete classification and comparison. A few alloys which are of special service in the arts have been well studied by those who have had occasion to use them, with a view to learn their mechanical properties, not as a matter of scientific interest, but as an actual necessity. This has been the case especially with the various gun-metals, upon which many experiments have been made under authority of the different governments, so that among all the alloys our knowledge of the gun-metals is the most extensive and accurate. In like manner the properties of journal and anti-friction metals have been investigated by those who are concerned in their manufacture and use.

With these, and a few other exceptions, however, our information on the mechanical properties of the alloys is very meager. It will be the endeavor of the Committee, as far as possible, to supply this manifest want by a series of experiments on a large number of alloys, testing them for all the mechanical properties above named.

The hardness of some of the alloys has been investigated by Calvert and Johnson.† They used an apparatus for determining the hardness, which consists, chiefly, of a conical steel point of a certain size, which is pushed into the material whose hardness is to be determined a given distance by means of weights applied at the end of a lever. The relative hardness is shown by the weight required for the different materials.

A somewhat similar apparatus was used by Major Wade ‡ in determining the hardness of gun-metal, but he used a diamond-shaped point and a fixed weight, determining the relative hardness by the distance which the point was pushed into the metal. General Uchatius,§ in experiments for the Austrian Government, used an indenting tool, which was forced into the metal to be tested by a weight of 4.4 pounds falling through a height of 9⅜ inches. The shorter the cut made by the indenting tool the greater was the hardness.

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* Scientific American, vol. 33, 1875, p. 135.

† Phil. Mag., vol. 17, 1859, pp. 114–121.

‡ Report of Experiments on Metals for Cannon, Phila., 1856.

§ Ordnance Notes No. XL, Washington, D. C., 1875.

Mallet,* in 1842, in his experiments on the alloys of copper and tin and copper and zinc determined their tensile strength, and also the order of their ductility, malleability, and hardness. In his work on the Construction of Artillery,† published in 1856, the same author discusses the physical and mechanical properties of gun-metal, showing the effects of sudden and of rapid cooling, and the deteriorating effect of small proportions of a third metal, such as iron, zinc, lead, or antimony.

In regard to the extent of our knowledge upon these subjects, he remarks: "Gun-metal, probably the very earliest used material for cannon, is that which has received the least improvement or systematization of our knowledge as to its use, up to the present time; the archæologist finds the rude weapons of Scandinavian, Celtic, Egyptian, Greek, and Roman warfare formed of nearly the same alloys of copper and tin, and in about the same proportions as the cannon of to-day."

The circumstances of chief difficulty and importance in the manipulation of gun-metal, as affecting the production of cannon, are:

1st. The chemical constitution of the alloy, as influencing the balance of its hardness, rigidity, or ductility, and tenacity.

2d. Its chemical constitution, and what other conditions, influence the segregation of the cooling mass of the gun when cast into two or more alloys of different and often variable composition.

3d. The effects of rapid and of slow cooling, and of the temperature at which the metal is fused and poured.

4th. The effects due to repeated fusions, and to foreign constituents, in minute proportions entering into the alloy.

The circumstances of manipulation, as above named, have already been shown to have a vast influence upon nearly all the properties of the alloys, and their study is of the greatest importance, not only in reference to gun-metals, but to all alloys which may be used as materials of construction.

In connection with the subject of gun-metal, the experiments lately made by General Uchatius‡ for the Austrian Government are of interest. He found that the tenacity, elasticity, and hardness of bronze were increased to an extraordinary degree by driving a series of conical steel mandrels or plugs, gradually increasing in size, into the bore of the gun. The metal in the interior of the gun was thus stretched or strained much beyond its elastic limit, and was thereby given a new molecular condition, which enables it better to resist both the expansive force of the exploded powder and the abrading effects of the shot.

The results of the experiments of General Uchatius have been communicated to the Ordnance Department of the United States by Col. T. T. S. Laidley, U. S. A., who calls attention to the fact that experiments were made upon bronze, with a view to improve its quality for guns, by Mr. S. B. Dean, of Boston, in 1868–'69, at which time he used the identical mode of improving the bronze adopted by General Uchatius some four years later. Patents for the improvement were secured in May, 1869, not only in this country, but also in England, France, and Austria. The want of funds rendered it necessary for Mr. Dean's experiments to be discontinued.

Bischof§ describes an apparatus for determining the qualities of the malleable metals and alloys, which is based upon the principle that "superior qualities of malleable metals and alloys are characterized by their being able permanently to extend in all directions by rolling or hammering without rupture, while inferior qualities break before reaching the maximum of extension which the former can endure." His apparatus is used to bend the metal or alloy to be tested, which is of a certain size and shape, in contrary directions through a certain angle. The oftener the piece can be so bent without breaking the better is its quality.

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* Phil. Mag., vol. 21, 1842, pp. 66–68.

† Mallet, Construction of Artillery, London, 1856, pp. 80–101.

‡ Ordnance Notes No. XL, Washington, D. C., 1875.

§ British Assoc. Reports, 1870, pp. 209, 210.

LIST OF AUTHORITIES.

ABEL. Notes on Compounds of Copper and Phosphorus. By F. A. Abel, F. R. S. British Assoc. Reports, 2, 1865, pp. 27, 28.

Describes experiments made upon several compounds of copper and phosphorus. Copper with 0.75 per cent. of phosphorus was found to have a tensile strength of 45,000 pounds per square inch.

ABEL. *Legirungen von Gold, Silber und Kupfer mit Cadmium, für Juwelierarbeiten.* Alloys of gold, silver, and copper with cadmium, for jewelry. Dingler's *Journal*, vol. 167, 1863, pp. 288, 289.

ABEL and FIELD. Some Results of the Analyses of Commercial Coppers. By F. A. Abel, F. R. S., and Frederick Field, F. R. S. E. Jour. Chem. Soc., vol. 14, 1862, pp. 290–303.

Contains a complete table of the analyses of a large number of commercial coppers, with descriptions of the methods of analyses.

ALLEN. On the Alloys of Copper, Tin, Zinc, Lead, and other Metals with Manganese. By J. Fenwick Allen, F. C. S. British Assoc. Reports, 2, 1870, p. 50.

Certain mixtures of manganese with copper and zinc are said to possess advantages over both German silver and yellow metal.

ANDERSON. Anderson's Strength of Materials and Structures. 1 vol. London, 1872.

Contains an account of the mechanical properties of copper and several of its alloys, with the experiments at Woolwich on the strength of copper, bronze, and sterro-metal.

BABBITT. Babbitt Metal. Scientific American, vol. 12, 1856, p. 326. U. S. Patents, July 17, 1839.

A patent was issued to Isaac Babbitt, July 17, 1839, for the construction of boxes for the journals, wheels, and axles of carriages, but it does not embrace a peculiar metal, as is generally supposed. It simply covers the lining of a hard shell of metal with a softer metal for the bearings of axles.

BABINET. *Rapport sur deux mémoires de Wertheim intitulés Recherches sur l'élasticité.* Report on two memoirs of M. Wertheim entitled Researches on elasticity. *Comptes Rendus*, vol. 18, 1844, pp. 921–932.

(See Wertheim.)

BARRUEL. *Sur un nouvel alliage d'argent remarquable par sa dureté.* On a new alloy of silver remarkable for its hardness. By Germain Barruel. *Comptes Rendus*, vol. 35, 1852, p. 759.

BAUER. Action of Sulphuric Acid on Lead and its Alloys. By A. Bauer. Published recently in the *Berichte der deutschen chemischen Gesellschaft.* Scientific American, vol. 33, p. 135, August 28, 1875.

Berthier. *Legirungen von Zinc und Eisen.* Alloys of zinc and iron. Liebig's *Annalen*, vol. 40, 1841, pp. 186–189.

Besley. An Improved Manufacture of Metallic Alloy. British patent, June 28, 1855, No. 1478.

Applicable to the casting of type and other metals. Contains 100 parts lead, 30 antimony, 20 tin, 8 nickel, 5 cobalt, 8 copper, 2 bismuth.

Bischof. On a New System of Testing the Quality of the Malleable Metals and Alloys. By Gustav Bischof, jr. British Assoc. Reports, 2, 1870, pp. 209, 210.

Describes an apparatus termed a "Metallometer," used for determining the quality of the malleable metals and alloys by bending them in contrary directions.

Bischoff. *Das Kupfer und seine Legirungen, mit besonderer Berücksichtigung ihrer Anwendung in der Technick.* Dr. Carl Bischoff, Berlin, 1865.

Bolley. *Essais et recherches chimiques.* By Professor P. A. Bolley. 1 vol., 748 pp. Paris, 1869.

Chapter XIV, on alloys, describes a large number of useful alloys, with their composition.

——— Physical Properties of some Alloys of Tin and Lead. Jour. Chem. Soc., vol. 15, 1862, pp. 30–36. Dingler's *Journal*, vol. 162, 1861, p. 217.

Extracts from a prize essay by G. Pillichody, of Berne. Gives the fusing points and specific gravities.

——— *Die bekannten technisch gebrauchten Metalllegirungen.* The known technically employed alloys. Dingler's *Journal*, vol. 129, 1853, pp. 438–444.

Contains tables of a large number of useful alloys.

Boussingault. *Note sur la combinaison du silicium avec le platine, et sur sa présence dans l'acier.* Note on the combination of silicon with platinum, and on its presence in steel. *Ann. de Chim.*, vol. 16, 1821, pp. 5–15.

——— On the Alloys of Steel. Quart. Jour. Science, vol. 12, 1822, pp. 316–318.

Brooman. *Neue Metalllegirung für Glocken,* etc. New alloy for bells, etc. By R. A. Brooman. Dingler's *Journal*, vol. 173, 1864, pp. 285–286. From the London Journal of Arts, May, 1864, p. 264.

Brunner. *Analyse von Metalllegirungen.* Analysis of alloys. By C. Brunner. Erdmann's *Journal*, vol. 58, 1853, pp. 445–446.

Calvert and Johnson. On Alloys. By F. Crace Calvert, F. R. S., and Richard Johnson, F. C. S. British Assoc. Reports, 2, 1855, pp. 50–51. Phil. Mag., vol. 10, 1855, pp. 240–251. *Comptes Rendus*, vol. 41, 1855, pp. 529–532. Erdmann's *Journal*, vol. 67, 1856, pp. 212–216. Dingler's *Journal*, vol. 138, 1855, p. 282.

Account of the beginning of a series of experiments on the alloys. Alloys of the following metals are described: Iron and potassium, iron and aluminum, iron and zinc, zinc, tin, and copper. This paper also describes the action of acids on some of the alloys.

Calvert. On the Expansion of Metals, Alloys, and Salts. By F. Crace Calvert, F. R. S. British Assoc. Reports, 2, 1858, pp. 46, 47.

Marked differences between results and those of other experimenters. In all the alloys examined the expansion was far less than that deduced from their equivalents.

CALVERT and JOHNSON. On the Relative Power of Metals and Alloys to Conduct Heat. By F. Crace Calvert, F. R. S., and Richard Johnson, F. C. S. Phil. Trans., 1858, pp. 349–368. Phil. Mag., vol. 16, 1858, pp. 381–383. *Comptes Rendus*, vol. 47, 1858, pp. 1069–1072.

An extensive research on the conductivity of metals and alloys.

——— On the Hardness of Metals and Alloys. Phil. Mag., vol. 17, 1859, pp. 114–121. Jour. Frank. Inst., vol. 37, 1855, pp. 198–203. Pogg. *Annalen*, vol. 118, 1859, pp. 575–582.

Description of new apparatus used and results obtained on several metals and alloys.

——— On the Specific Gravities of Alloys. Phil. Mag., vol. 18, 1859, pp. 354–359. British Assoc. Reports, 1859, pp. 66, 67.

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——— On the Conductivity of Mercury and the Amalgams. Phil. Trans., 1859, pp. 831–835. Proc. Roy. Soc., vol. 10, 1859–'60, pp. 14–16.

The conductivity of the fluid amalgams was found to be nearly the same as that of pure mercury, which is lower than that of any other metal.

——— Action of Acids upon Metals and Alloys. Jour. Chem. Soc., vol. 19, 1866, pp. 434–454.

Action of sulphuric, hydrochloric, and nitric acids described. Some curious and unexpected results were obtained.

CALVERT and LOWE. On the Expansion of Metals and Alloys. By F. Crace Calvert, F. R. S., and G. Cliff Lowe, esq. Chemical News., vol. 3, 1861, pp. 315–317, 357–359, 371–373. Phil. Mag., vol. 20, 1860, pp. 230–233.

The results obtained agreed with those of other experimenters only where commercial metals were used. When pure metals were used the results differ.

CARON. *Alliage de barium, de strontium, de calcium et de sodium.* Alloys of barium, strontium, calcium, and sodium. *Comptes Rendus*, vol. 48, 1859, pp. 440, 442.

CHAUDET. *Note contenant quelques expériences relatives à l'action de l'acide hydrochlorique sur les alliages de cuivre et d'étain.* Note containing some experiments relative to the action of hydrochloric acid on the alloys of copper and tin. By M. Chaudet. *Ann. de Chim.*, vol. 7, 1817, pp. 275–283.

——— *Note contenant quelques expériences relatives à l'action de l'acide hydrochlorique sur les alliages d'étain et d'antimoine.* Note, &c., action of hydrochloric acid on the alloys of tin and antimony. *Ann. de Chim.*, 1816, vol. 3, pp. 376–386.

——— *Note contenant quelques expériences relatives à l'action de l'acide hydrochlorique sur les alliages d'étain et de bismuth.* Note, &c., action of hydrochloric acid on the alloys of tin and bismuth. *Ann. de Chim.*, vol. 5, 1817, pp. 142–149.

CLARKE. The Constants of Nature. Part 1. Edited by Frank Wigglesworth Clarke. Published by the Smithsonian Institution, Washington, D. C., 1873.

Contains a very complete and valuable table of the specific gravities of the alloys, with the melting points of a few, and the names of the authorities.

COOKE. On Stibiotrizincyle and Stibiobizincyle, two New Compounds of Zinc and Antimony, with some Remarks on the Decomposition of Water by the Alloys of these Metals. By Josiah P. Cooke, jr. Am. Jour. Arts and Sci., vol. 18, 1854, pp. 229–237. Erdmann's *Journal*, vol. 64, 1855, pp. 90–92.

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——— On an Apparent Perturbation of the Law of Definite Proportions observed in the Compounds of Zinc and Antimony. Am. Jour. Art and Sci., vol. 20, 1855, pp. 222–238.

——— Crystalline Form not Necessarily an Indication of Definite Chemical Composition; or, On the Possible Variation of Constitution in a Mineral Species independent of Isomerism. Am. Jour. Art and Sci., vol. 30, 1860, pp. 194–204. Phil. Mag., vol. 19, 1860, pp. 405–416. Erdmann's *Journal*, vol. 80, 1860, pp. 411–418.

Contains some deductions from the observations made on the crystallization of the alloys of zinc and antimony.

CROOCKEWIT. *Ueber chemische Metallverbindungen.* On chemical combinations of metals. Erdmann's *Journal*, vol. 45, 1848, pp. 87–93. Liebig's *Annalen*, vol. 18, 1848, pp. 289–293.

Contains the specific gravities of a number of alloys, noting the difference of specific gravity in the top and bottom of a bar cast vertically.

D'ARCET. *Note sur l'essai des alliages de platine et d'argent, et sur l'application que l'on peut faire de ce procédé à l'exploitation des mines d'argent contenant du platine.* Note on the tests of alloys of platinum and silver and on the application which might be made of this process in the working of mines of silver ores containing platinum. By M. D'Arcet. *Ann. de Chim.*, 1814, vol. 89, pp. 135–149.

——— Observations on a note by Stanislas Julien, "*Procédé des Chinois pour fabriquer les tam-tams et les cymbales.*" Process of the Chinese for the manufacture of tam-tams and cymbals. *Ann. de chim.*, vol. 54, 1833, pp. 331–335.

——— *Sur l'altération qu'éprouvent de la part des substances culinaires les alliages de cuivre, de zinc et de nickel, connus sous les noms de maillechort, melchior, argentan.* On the alterations produced in culinary substances by the alloys of copper, zinc, and nickel, known under the names of maillechort, melchior, argentan. *Jour. de pharm.*, vol. 23, 1837, pp. 223–227.

DEBRAY. *Des alliages d'aluminium.* Alloys of aluminum. By M. H. Debray. *Comptes rendus*, vol. 43, 1856, pp. 925–927. Dingler's *Journal*, vol. 143, 1857, p. 42.

DE LA RUE. On a Crystallized Alloy of Zinc, Lead, and Copper. By Warren de la Rue. Phil. Mag., vol. 27, 1845, pp. 370–372. Erdmann's *Journal*, vol. 37, 1846, pp. 126–127.

The alloy was obtained from the worn-out amalgamated zinc plates used in the voltaic battery.

DE RUOLZ and DE FONTENAY. *Darstellung einer Metalllegirung, welche fast für alle Zwecke benutzt werden kann, wozu gewöhnlich Silber angewendet wird.* Description of an alloy which can be used for all purposes for which silver is generally used. Dingler's *Journal*, vol. 134, 1854, pp. 215–216.

——— On Phosphoric Bronze. *Comptes Rendus*, vol. 73, 1871, pp. 1468–1470.

MM. H. de Ruolz and A. de Fontenay presented a communication to the French Academy of Sciences, in which, after referring to a paper by Levi and Künzel (see Levi and K., Essais, &c.), they claim that they used the identical processes described by these authors in experiments made for the French Government from 1854 to 1859, but that they had kept them secret up to this time (1871). They claim that they were the first to use phosphorus in bronze for artillery, and also manganese for the same purpose, whether alone or associated with other metals.

Deville. *Méthode d'analyse des bronzes et des laitons.* Method of analysis of bronze and brass. By Henri St. Claire Deville. *Ann. de Chim.*, vol. 43, 1855, pp. 473–477.

——— *Recherches sur les métaux, et en particulier sur l'aluminium, et sur une nouvelle forme de silicium.* Researches on the metals, and in particular on aluminum, and on a new form of silicon. *Ann. de Chim.*, vol. 43, 1835, pp. 5–36.

——— *De l'aluminium, ses propriétés, sa fabrication et ses applications.* Concerning aluminum, its properties, manufacture, and applications. 1 vol. Paris, 1859.

Dick. Improvement in Alloys of Copper for Bearings. By C. J. A. Dick. United States patent, April 9, 1872, No. 125549.

Claims the addition of a limited proportion of lead, with or without other metals, to phosphorized alloys of copper and tin, making them especially valuable for journal bearings.

Dingler. Dingler's *Polytechnisches Journal* contains several short articles on alloys, among which are: Vol. 27, p. 273, and vol. 29, p. 442, 1828. Different alloys: Vol. 123, 1852, pp. 267–277. Preparation of Britannia metal: Vol. 134, 1854, pp. 313–314. White journal metal used on Hanoverian railways: Vol. 139, 1856, p. 464. Alloys for piston rings of locomotives: Vol. 211, 1874, p. 322. Phosphor-bronze.

Dunlevie. *Lagermetall.* Metal for journal bearings. Dingler's *Journal*, vol. 177, 1865, pp. 326, 327. London Journal of Arts, 1865, p. 205.

Alloy containing tin, zinc, copper, and antimony heats very little by friction.

Dussaussoy. *Résultat des expériences faites par ordre de Son Excellence le mareschal Duc de Feltre, ministre de la Guerre, sur les alliages de cuivre, d'étain, de zinc et de fer, considérés sous le rapport de la fabrication des bouches à feu, et autres objets semblables.* Result of experiments made, &c., on the alloys of copper, tin, zinc, and iron, considered with reference to the manufacture of cannon, and other like objects. By M. Dussaussoy. *Ann. de Chim.*, vol. 5, 1817, pp. 113–121, 225–234.

Eclectic. Van Nostrand's Eclectic Engineering Magazine. 1869, p. 172. Alloys fusible at specified temperatures. 1873, vol. 8, p. 570. White metal for machinery.

For crank and connecting rod bearings, 90 tin, 8 antimony, 2 copper. For pivots, slide valves, &c., 78.5 tin, 11.5 antimony, 10 copper. For locomotives (Swiss), 80 tin, 10 antimony, 10 copper.

Engineer. Phosphorized Bronze and other Alloys as a Material for Artillery. Engineer, London, vol. 33, 1872, pp. 127, 128, 145, 146, 179, 181.

A valuable article, giving results of experiments.

Faraday. *Lettre au Prof. De la Rive sur les alliages que forme l'acier avec différents métaux.* Letter to Prof. De la Rive on the alloys which steel forms with different metals. *Bibliothèque Universelle*, vol., 14, 1820, pp. 209-215. (See Stodart and Faraday.)

Franklin Institute. Journal of the Franklin Institute, vol. 67, 1874, pp. 293–296. Describes the Ferro-Manganese made by the Terre Noire Company of France, and used in the Bessemer process. Vol. 67, 1874, pp. 160–161. Uses of phosphor-bronze.

Forbes. On the Chemical Examination of some Alloys of Copper and Zinc. By David Forbes, F. G. S., &c. Chemical Gazette, 1854, p. 393. British Assoc. Reports, 2, 1854, p. 67.

Describes a separation of compounds in ordinary brass-making, two alloys being found, one of a deep yellow color and malleable, and the other of a brilliant white and brittle.

Fremy. *Note sur le chrome cristallizé et sur les alliages d'aluminium.* Note on crystallized chromium and on aluminum alloys. *Comptes Rendus*, vol. 44, 1857, p. 632.

Gedge. Improvements in the Manufacture of Metallic Compounds. British patent, 1853, Nov. 12, No. 2626.

——— Alloys of Copper, Zinc, and Iron for Shipbuilding. Dingler's *Journal*, vol. 158, 1863, p. 273.

Genth. Analysis of Chinese Alloys. By F. A. Genth. Jour. Frank. Inst., vol. 36, 1858, p. 261. Phil. Mag., vol. 16, 1858, pp. 420–426.

Some Chinese coins were found to contain chiefly copper and zinc, with small traces of other metals. As many as eight metals were found in one alloy.

Gersheim. *Erfindung einer Metallcomposition, die sich durch Stossen und Drücken so weich und plastisch machen lässt, dass sie mit den Fingern in jede beliebige Form gedrückt werden kann.* Discovery of a metallic compound which can be made so soft and plastic by pounding and pressing that it can be worked into any form by the fingers. Dingler's *Journal*, vol. 147, 1858, pp. 462, 463.

Gersdorff. *Ueber das Packfong.* On Packfong. By H. V. Gersdorff. Pogg. *Annalen*, vol. 8, 1826, pp. 103–106.

Graham. The Brassfounder's Manual. By Walter Graham. 1 vol. London, 1870.

Instructions for modeling, pattern-making, molding, alloying, turning, filing, bronzing, &c.

Graham. On the Melting Points of Easily Fusible Alloys. *Polytechnisches Centralblatt*, 1874, p. 923.

Guettier. *Guide pratique des alliages métalliques.* Practical guide of the metallic alloys. By A. Guettier, director of founderies, &c. 1 vol. Paris, 1865. The same, translated into English. By A. A. Fesquet. 1 vol. Phila., 1871.

A valuable and concise treatise on the alloys, describing their properties, and giving directions for their manufacture.

——— *Praktische Untersuchungen über technische Metalllegirungen.* Practical researches on technical alloys. By A. Guettier. Dingler's *Journal*, vol. 114, 1849, pp. 128–135, 196–279.

Hachette. *Historische Notiz über Stahllegirungen und Damaszirung.* Historical note on steel alloys and Damascening. Dingler's *Journal*, vol. 5, 1821, pp. 435–438.

Hamilton and **Parker.** New Metal in Imitation of Gold, called Mosaic Gold. Jour. Frank. Inst., vol. 1, 1826, pp. 139, 140; vol. 2, p. 215. Dingler's *Journal*, vol. 21, 1826, pp. 234, 235.

Haswell. Engineer's Pocket-Book. By C. H. Haswell.

Table of composition of several useful alloys.

Hatchett. Experiments and Observations on the various Alloys, on the specific Gravity, and on the comparative Wear of Gold; being the Substance of a Report made to the Committee of the Privy Council appointed to take into consideration the State of the Coins of the Kingdom, &c. By Charles Hatchett, F. R. S. Phil. Trans., 1803, pp. 43–104.

Hervé. *Nouveau manuel complète des alliages métalliques.* New complete manual of the metallic alloys. By A. Hervé. 1 vol. Paris, 1839.

Contains the preparation of the alloys, their principal properties, their use, their existence in nature, their analysis, &c.

Iron Age. March 27, 1873, p. 1. Melting Points of Lead and Tin Alloys. December 10, 1874. The deposition of alloys.

Jacoby. Improvement in Metallic Alloy. By J. E. Jacoby. British patent, October 7, 1873, No. 3246. Chemical News, vol. 30, 1874, p. 10.

Alloys containing from 70 to 73 per cent. of copper, 9 to 11 per cent. tin, 15 to 20 per cent. lead, and from 0.05 to 1 per cent. zinc for journal bearings and like purposes.

Jacobi. *Vorzügliche Legirung für Zapfenlager.* Excellent alloy for journal boxes. By R. Jacobi. Dingler's *Journal*, vol. 167, 1863, p. 463.

Alloy of 5 parts copper, 85 tin, and 10 antimony.

Jahresbericht. *Jahresbericht über die Leistungen der chemischen Technologie*, von Rudolf Wagner, Leipzig.

Contains several articles on alloys. Phosphor-bronze is discussed in the numbers for 1870, 1871, 1872, and 1873.

Johnson. Alloy of Wrought and Cast Iron to Replace Steel. Practical Mechanics' Journal, 2d series, vol. 5, p. 207.

Joule. On some Amalgams. By J. P. Joule, F. R. S., British Association Reports, 2, 1850, p. 55. Jour. Chem. Soc., 1, 1863, pp. 378–387.

Describes amalgams of iron, copper, silver, platinum, zinc, lead, and tin.

Julien. *Procédé des Chinois pour fabriquer les tam-tams et les cymbales.* Process of the Chinese for making tam-tams and cymbals. By Stanislas Julien. *Ann. de chim.*, vol. 54, 1833, pp. 329–331.

Karsten. *Untersuchungen der englischen Metallurgen über die Verbesserung des Stahls durch Legirung mit anderen Metallen.* Researches of the English metallurgists on the improvement of steel when alloyed with other metals. By C. J. B. Karsten. *Karsten Archiv f. Bergbau*, vol. 9, 1825; pp. 322–363.

——— *Ueber Metalllegirungen, besonders über die Legirung aus Kupfer und Zink.* On alloys, especially those of copper and zinc. Dingler's *Journal*, vol. 72, 1839, pp. 128–132. Pogg. *Annalen*, vol. 46, 1839, pp. 160–165.

——— *Ueber Kupfer-Zinn-Legirungen und deren Verhalten beim Glühen.* On alloys of copper and tin, and their behavior when heated. Schweigger Journ., vol. 66, 1832, pp. 255–286, 386–401. Jour. Frank. Inst., vol. 20, 1850, pp. 340–343.

Kerl. *Repertorium der technischen Literatur.* A list of scientific papers published between the years 1854 and 1868.

Vol. 2, pp. 94–97. Under the head of *Metalllegirungen* is found a list of one hundred papers by various authorities, having more or less reference to the alloys.

Kneiss. *Legirung für Maschinenlager.* Alloy for machine-bearings. Dingler's *Journal*, vol. 158, 1860; p. 236.

Alloy of 3 parts copper, 40 zinc, 42 lead, 15 tin.

Knight. Knight's American Mechanical Dictionary.

Article on alloys. General description, very full and correct.

Kopp. *Ungleiche Mischung von Metalllegirungen in geschmolzenem Zustande.* Unequal mixture of alloys in the molten state. By Hermann Kopp. Liebig's *Annalen*, vol. 40, 1841, pp. 184–186.

——— *Dichtigkeit des Cadmium Amalgams.* Density of cadmium amalgams. Liebig's *Annalen*, vol. 40, 1841, p. 186.

——— Expansion of some Solid Bodies by Heat. Phil. Mag., vol. 3, 1852, pp. 268–270. Liebig's *Annalen*, vol. 81, 1852, pp. 1–67.

KOPP. Copper and Zinc Alloy. By M. E. Kopp. Chemical News, vol. 3, 1861, p. 91.

Alloy of 60 parts copper, 38.15 zinc, 1.50 iron, remarkable for its malleability.

KÜNZEL. (See Levi and Künzel.)

KUPFFER. *Note sur la pesanteur spécifique des alliages et leur point de fusion.* Note on the specific gravities of the alloys and their points of fusion. *Ann. de chim.*, vol. 40, 1829, pp. 285–303. Quart. Jour. Sci., vol. 2, 1829, pp. 185, 186.

Describes experiments on the specific gravities and points of fusion of the alloys and amalgams of tin and lead.

LAFOND. *Ueber die Bronzen und andere Legirungen.* On bronzes and other alloys. Dingler's *Journal*, vol. 135, 1855, pp. 269–276.

A list of a number of alloys, chiefly of copper, tin, lead, and antimony, with a description of their properties and uses.

LARKIN. The Brass and Iron Founders' Guide. By James Larkin. 1 vol. Phila., 1874.

A concise treatise on brass founding and molding; the metals and their alloys, &c.

LAUGIER. *Analyse de quelques alliages de bismuth.* Analysis of some alloys of bismuth. *Ann. de chim.*, vol. 36, 1827, pp. 332–334. Dingler's *Journal*, vol. 27, 1828, p. 240.

LEVI and KÜNZEL. *Essais sur l'emploi de divers alliages, et spécialement du bronze phosphoreux, pour la coulée des bouches à feu.* Experiments on the use of various alloys, and especially of phosphoric bronze, for the casting of cannon. By MM. Montefiore Levi and C. M. Künzel. *Comptes Rendus*, vol. 73, 1871, pp. 530–534.

——— The same, translated into English by John D. Brandt, chief clerk Bureau of Ordnance, Navy Department, United States. 1vol. Washington, Government Printing Office, 1872.

Contains complete tables of a valuable series of experiments on metals for cannon. Bronzes containing manganese, nickel, iron, zinc, and phosphorus were experimented upon.

——— Bronze Alloy. United States patents granted to G. M. Levi and C. M. Künzel, May 23, 1871, No. 115220, and Nov. 14, 1871, No. 120984.

LEVI. On Phosphoric Bronze and its Principal Industrial Uses. By M. C. Montefiore Levi. Amer. Chemist, vol. 5, 1874, pp. 178–180. Dingler's *Journal*, vol. 211, 1874, p. 322.

LEVOL. *Mémoires sur le dosage de l'arsenic dans les métaux usuels et dans leur alliages.* Memoirs on the amount of arsenic in the usual metals and their alloys. *Ann. de Chim.*, vol. 16, 1846, pp. 493–504.

——— *Note sur une nouvelle cause d'hétérogénéité des alliages d'argent et de cuivre produit par absorption d'oxygène.* Note on a new cause of heterogeneity of the alloys of silver and copper, produced by the absorption of oxygen. *Revue Scientifique*, vol. 10, 1846, pp. 211–213.

——— *Mémoire sur les alliages métalliques considérés sous le rapport de leur composition chimique.* Memoir on the alloys considered with reference to their chemical composition. *Ann. de Chim.*, vol. 36, 1852, pp. 193–224; vol. 39, 1853, pp. 163–184. *Journ. de Pharm.*, vol. 17, 1850, pp. 111–114. Erdmann's *Journal*, vol. 60, 1853, pp. 449–456.

——— *De l'influence du bismuth sur la ductilité de cuivre.* On the influence of bismuth on the ductility of copper. Paris, *Bull. de la Soc. Encour.*, vol. 4, 1853, pp. 746–748.

LEVOL. *Legirung von Gold und Silber*, Kupfer, *Silber mit Blei.* Alloys of gold and silver, gold and copper, silver and lead. Dingler's *Journal*, vol. 136, 1855, pp. 453–454. *Ann. de Chim.*, vol. 39, p. 163.

——— *Legirung von Silber mit Kupfer.* Alloys of silver and copper. Dingler's *Journal*, vol. 130, 1853, pp. 128–129.

LIPOWITZ. *Ueber Wood's leichtflüssiges Metall.* On Wood's easily-fusible metal. Dingler's *Journal*, vol. 158, 1860, pp. 376, 377.

Describes several fusible alloys which melt at points between 60° and 98° C.

MALLET. Chemical and Physical Properties of the Atomic Alloys of Copper and Zinc, and Copper and Tin. By Robert Mallet, F. R. S. Phil. Mag., vol. 21, 1842, pp. 66–68. Dingler's *Journal*, vol. 85, 1842, p. 378.

Tables giving the chemical composition, specific gravity, color, fracture, cohesion, and order of ductility, malleability, hardness, and fusibility of the alloys of copper and zinc and copper and tin.

——— On a Metallic Alloy in an Unusual State of Aggregation. Phil. Mag., vol. 23, 1848, p. 141.

A new alloy was formed by portions of abraded brass in a journal bearing being forced into close contact. It was of identical composition with the original brass, but was black in color, and had only one-fifteenth of its strength.

——— On the Physical Conditions involved in the Construction of Artillery. 1 vol. London, 1856.

Contains a discussion of the properties of bronze as a material for cannon, with the effects of rapid and of slow cooling, and the effects due to repeated fusion and to the presence of impurities in minute proportions.

MATTHIESSEN. On the Specific Gravities of Alloys. By A. Matthiessen, F. R. S. Phil. Trans., 1860, pp. 177–184. Proc. Roy. Soc., vol. 10, 1859–'60, pp. 12, 13. Pogg. *Annalen*, vol. 110, 1860, pp. 21–37.

An extensive research upon the specific gravities of 18 different series of alloys.

——— On an Alloy which may be used as a Standard of Electrical Resistance. Phil. Mag., vol. 21, 1861, pp. 107–115.

Recommending the alloy of 2 parts gold and 1 part silver as a standard of electrical resistance.

——— Note on Professor Bolley's communication "On some Physical Properties of the Alloys of Tin and Lead." *Jour. Chem. Soc.*, vol. 15, 1862, pp. 105–107.

Criticism of Professor Bolley's method of finding the calculated specific gravities.

——— On the Electric Conducting Power of Alloys. Phil. Trans., 1860, pp. 161–176. Proc. Roy. Soc., vol. 10, 1859–'60, pp. 205–206. Pogg. *Annalen*, vol. 110, 1860, pp. 190–221.

A valuable research on the electric conducting power of 18 different series of alloys.

——— Report on the Chemical Nature of Alloys. British Assoc. Reports, 1, 1863, pp. 37–48.

Complete classification of the alloys according to their chemical nature, as deduced chiefly from experiments upon their conductivity.

——— On the Variation of the Electrical Resistance of Alloys due to a change of Temperature. British Assoc. Reports, 2, 1863, pp. 124–127. Electrician, vol. 4, 1863, pp. 285, 286, 296.

——— On the Electrical Permanence of Metals and Alloys. British Assoc. Reports, 1863, 2 pp. 127–130. Electrician, vol. 4, 1863, pp. 296, 297, vol. 5, p. 5.

MATTHIESSEN. On Alloys. Jour. Chem. Soc., vol. 5, 1867, pp. 201–220.

A discourse on the general nature and properties of alloys, and reasons deduced from experiment for the author's adoption of certain views on the subject.

MATTHIESSEN and VON BOSE. On the Lead-Zinc and Bismuth-Zinc Alloys. By A. Matthiessen, F. R. S., and M. Von Bose. Proc. Roy. Soc., vol. 11, 1860–'62, pp. 430–433. Erdmann's *Journal*, vol. 84, 1861, pp. 323–326.

Lead and zinc do not alloy in all proportions. The results show that lead will dissolve only 1.6 per cent. of zinc and zinc only 1.2 per cent. lead; that zinc will dissolve only 2.4 per cent. of bismuth and bismuth from 8.6 to 14.3 per cent. zinc.

——— On some Gold-Tin Alloys. Proc. Roy. Soc., vol. 11, 1860–'62, pp. 433–436. Erdmann's *Journal*, vol. 84, 1861, pp. 319–322.

Describing some experiments on the crystallization of some of the alloys of gold and tin.

MATTHIESSEN and VOGT. On the Influence of Temperature on the Electric Conducting Power of Alloys. By A. Matthiessen, F. R. S., and Carl Vogt. Phil. Trans., 1864, pp. 167–200.

A research on the electric-conducting power of a large number of alloys at different temperatures.

MATTHIESSEN and HOLZMANN. On the Effect of the Presence of the Metals and Metalloids on the Electric Conductivity of Pure Copper. By A. Matthiessen, F. R. S., and M. Holzmann. Phil. Trans., 1860, pp. 85–92. Pogg. *Annalen*, vol. 110, 1860, pp. 222–234.

MAUMENÉ. *Note sur les bronzes du Japan.* Note on the bronzes of Japan. By E. G. Maumené. *Comptes Rendus*, vol. 80, 1875, pp. 1009, 1010. Scientific American, October 30, 1875, p. 281.

MICHEL. *Ueber krystallisirte Verbindungen von Aluminium mit Metallen.* On crystallized compounds of aluminum with metals. Liebig's *Annalen*, vol. 115, 1860, pp. 102–105. Erdmann's *Journal*, vol. 82, 1861, pp. 237, 238. Phil. Mag., vol. 20, 1860, p. 377.

Describes alloys of aluminum with tungsten, molybdenum, manganese, iron, nickel, and titanium.

MILLER. On the Form of an Alloy of Bismuth. By Wm. Hallows Miller. Phil. Mag., vol. 12, 1856, pp. 48, 49.

Describes crystallization of an alloy of bismuth containing nickel, copper, and sulphur.

MORIN. *Sur quelques bronzes de la Chine et du Japan à patine foncée.* On some bronzes of China and Japan with dark patina. By M. H. Morin. *Comptes Rendus*, vol. 78, 1874, pp. 811–814.

MUNTZ. Ship-Sheathing Metal. British patents, 1832, October 22, No. 6325. 1846, October 15, No. 11410. 1852, May 8, No. 14117. 1858, March 19, No. 572. 1858, May 21, No. 1134. London Journal of Arts, May, 1847, p. 268. Dingler's *Journal*, vol. 104, 1847, p. 465.

MUSHET. On the Alloys of Iron and Copper. By David Mushet. Phil. Mag., vol. 6, 1835, pp. 81–85. Dingler's *Journal*, vol. 56, 1835, p. 11.

The author claims to have established the practicability of alloying malleable iron with copper in every reasonable proportion.

——— On the Immersion of Copper for Bolts and Ship-Sheathing in Muriatic Acid as a Test of its Durability. Phil. Mag., vol. 6, 1835, pp. 444–447.

Unrefined copper was found to resist the action of muriatic acid better than pure copper. This was proved to be due to the presence of tin.

MUSHET. Alloys of Tungsten. Several patents for the same. See British Patent Reports. Abridgment of Specifications relating to Metals and Alloys. London, 1861.

MUSPRATT. Muspratt's Chemistry, vol. 1, pp. 533–553. Article on Copper Alloys.

A valuable article. Includes a description of the method of casting bronze guns, and the changes of density, hardness, &c., of bronze by tempering.

MUSSCHENBROEK. Musschenbroek is referred to by several writers as having made experiments upon alloys in the first part of the last century. See Encyclopædia Britannica; article, Strength. Also, Knight's Am. Mech. Dictionary.

NETKE. *Weissguss für Lager.* White casting for journals. Dingler's *Journal*, vol. 168, 1863, p. 74.

Alloy of 8 parts tin, 2 parts antimony, 1 part copper. Used by General Steam Navigation Company of London for wheel and propeller shafts, &c.

OXLAND. Improvements in Manufacture of Alloys containing Tungsten. British patent, 1857, December 18, No. 3114.

DE PARADIS. *Das Aich-Metall und das Sterro-Metall, zwei neue Metalllegirungen.* Aich-metal and sterro-metal, two new metallic alloys. Dingler's *Journal*, vol. 160, 1861, pp. 34–40.

Description of these two alloys and their mechanical properties.

PARKES. Several valuable alloys made by Mr. Parkes, described in Ure's Dictionary, vol. 1; article, Alloy. See, also, British Patents, Abridgment of Specifications relating to Metals and Alloys. London, 1861. Dingler's *Journal*, vol. 116, 1850, pp. 78–80. Mechanics' Magazine, vol. 51, p. 309.

PATENTS, U. S. General Index of Patents, 1790 to 1873, U. S. Patent Office.

Contains list of 53 patents having reference to alloys.

PATENTS, G. B. Abridgments of the Specifications relating to Metals and Alloys. Printed by order of the British Commissioner of Patents. London, 1861.

Contains abridgments of specifications of more than 100 patents of alloys, dating between 1664 and 1859.

PELIGOT. *Sur les alliages d'argent et de zinc.* On the alloys of silver and zinc. By Eugene Peligot. *Comptes Rendus*, vol. 58, 1864, pp. 645–651.

PERCY. On some of the Alloys of Tungsten. By John Percy, F. R. S. British Assoc. Reports, 2, 1848, p. 57.

Experiments on the economic use of tungsten in alloys. The results were unsatisfactory.

——— On Copper containing Phosphorus, with Details of Experiments on the Corrosive Action of Sea Water on some Varieties of Copper. British Assoc. Reports, 2, 1849, pp. 39, 40.

Describes an alloy containing copper 95.72, iron 2.41, phosphorus 2.41. On its being exposed to sea water for 9 months there was no loss of weight.

——— Metallurgy. Vol. 1. Fuel; Fire Clays; Copper; Zinc; Brass, etc. London, 1861.

Contains a valuable account of brass and other alloys of copper.

——— Metallurgy. Vol. 2. Iron and Steel. London, 1864; pp. 147–197.

Contains a very full account of the alloys of iron with other metals.

PERSON. *Solution d'une problème sur la fusion des alliages.* Solution of a problem on the fusion of the alloys. By C. C. Person. *Comptes Rendus*, vol. 23, 1846, pp. 626–629. Pogg. *Annalen*, vol. 70, 1847, pp. 388–392.

Experiments on some alloys of bismuth, lead, and tin. M. Person concludes that it is possible to assign in advance the heat necessary to fuse an alloy, if that required to fuse each of its components is known.

——— *Sur la chaleur spécifique anomale de certains alliages et sur leur réchauffement spontané après la solidification.* On the anomalous specific heat of certain alloys and their spontaneous reheating after solidification. *Comptes Rendus*, vol. 25, 1847, pp. 444–446. Liebig's *Annalen*, vol. 64, 1847, pp. 179–185.

PILLICHODY. On some Physical Properties of the Alloys of Tin and Lead. By G. Pillichody. Jour. Chem. Soc., vol. 15, 1862, pp. 30–32. *Polytechnisches Centralblatt*, 1862, p. 88.

POLAIN. *Ueber die Festigkeit der Phosphorbronze und über deren Anwendungen in der Industrie.* On the strength of phosphor-bronze, and on its applications in industry. By Alphons Polain. Dingler's *Journal*, 1875, vol. 217, pp. 482–494. Extract from the *Revue Universelle*, 1874, vol. 35, p. 595.

Account of experiments made in Belgium, France, and Germany on phosphor-bronze as a material for guns, and statement of its other industrial applications.

RAMMELSBERG. *Ueber einige krystallisirte Zinnhüttenproducte von Schlackenwalde und krystallisirte Legirungen im Allgemeinen.* On some crystallized products of tin furnaces and crystallized alloys in general. Pogg. *Annalen*, vol. 120, 1863, pp. 54–65.

REGNAULT. *Sur les chaleurs spécifiques des corps composés solides et liquides.* On the specific heat of solid and liquid compound bodies. By M. Victor Regnault. *Ann. de Chim.*, vol. 1, 1841, pp. 129–207. Erdmann's *Journal*, vol. 25, 1842, pp. 129–170. *Comptes Rendus*, vol. 12, 1841, pp. 56–83.

An extensive investigation on the specific heat of compound bodies, including the metallic alloys.

RENAULT. *Nouvelle méthode d'analyse quantitative applicable aux differents alliages.* New method of quantitative analysis, applicable to different alloys. By M. B. Renault. *Comptes Rendus*, vol. 60, 1865, p. 489. Dingler's *Journal*, vol. 176, 1865, pp. 371–374.

RICHE. *Recherches sur les alliages métalliques.* Researches on the metallic alloys. By M. Alf. Riche. *Comptes Rendus*, vol. 55, 1862, pp. 143–147. Dingler's *Journal*, vol. 170, 1863, pp. 113–114.

Experiments on the specific gravities, &c., of the alloys of tin and lead, lead and bismuth, antimony and lead, bismuth and tin.

——— *Recherches sur les alliages.* Researches on the alloys. *Comptes Rendus*, vol. 67, 1868, pp. 1138–1140.

A series of 15 alloys of copper and tin was examined with reference to their density, fusibility, and liquation.

——— *Recherches sur les alliages.* Researches on the alloys. *Comptes Rendus*, vol. 69, 1869, pp. 343–346.

Discussion of the effect of reheating and shock on the density of alloys of copper and tin.

——— *Note sur les bronzes des instruments sonores.* Note on the bronzes of sonorous instruments. *Comptes Rendus*, vol. 69, 1869, pp. 985, 986.

Mentions the ineffectual attempts made in France to imitate the cymbals and tam-tams of the Chinese.

RICHE. *Recherches sur les alliages.* Researches on the alloys. *Ann. de Chim.*, vol. 30, 1873, pp. 351–419. Dingler's *Journal*, 1874, vol. 213, pp. 150–159, 342–353, 514–523, 540; vol. 214, pp. 153–163, 243–248, 305–312.

An extensive and valuable research upon the alloys, especially those of copper and tin, with regard to their fusibility, liquation, and the modifications which they undergo under the influence of tempering, annealing, and mechanical operations.

RICHE and CHAMPION. *Fabrication des tam-tams et des cymbales.* Manufacture of tam-tams and cymbals. By MM. Alf. Riche and P. Champion. *Comptes Rendus*, vol. 70, 1870, pp. 85–88.

Describes the process of manufacture employed by the Chinese as seen by M. Champion at Shanghai.

ROBERTS. The Molecular Arrangement of the Alloy of Silver and Copper Employed for the British Silver Coinage. By W. C. Roberts, chemist to the mint. Brit. Assoc. Reports, 1871, p. 80.

The strips used for the coins contained more silver in the center than in the external edges by two parts in 1,000.

——— On the Liquation, Fusibility, and Density of Certain Alloys of Silver and Copper. Proc. Roy. Soc., vol. 23, 1875, pp. 481–495.

Contains an account of a valuable set of experiments on the melting-points of a series of alloys of silver and copper, on their liquation when rapidly or slowly cooled, and on their density when fluid.

RIEFFEL. *Mémoire sur les combinaisons chimiques du cuivre avec l'étain.* Memoir on the chemical combinations of copper with tin. *Comptes Rendus*, vol. 37, 1853, pp. 450–453. Erdmann's *Journal*, vol. 60, 1853, pp. 370–374.

RUDBERG. *Ueber eine allgemeine Eigenschaft der Metalllegirungen.* On a general property of the metallic alloys. Pogg. *Annalen*, vol. 18, 1830, pp. 240–249.

——— *Ueber die Wärmemengen in Metallgemischen.* On the quantities of heat in metallic compounds. Pogg. *Annalen*, vol. 71, 1847, pp. 460–463. Liebig's *Annalen*, vol. 64, 1847, pp. 183, 184.

SEMRAD and STERBENZ. Applications of Phosphor-Bronze. By G. Semrad and J. Sterbenz. *Deutsche Industriezeit.*, 1874, p. 323. Wagner's *Jahresbericht*, 1874, pp. 149, 150.

SCHUBARTH. Schubarth's *Repertorium der technischen Literatur.* A list of scientific papers published between the years 1823 and 1853. Contains, under the head of *Metalllegirungen*, a list of more than a hundred papers having reference to the alloys.

SHARMAN. White Metal. Scientific American, vol. 14, 1858, p. 25. Improved metallic compound, applicable to the manufacture of various useful and ornamental articles. British patent, 1857, October 13, No. 2621.

Tin, 16; lead, 3 or 4; zinc, 5. Said to be cheaper than most white metal.

SMITH. On the Liquation of Alloys of Silver and Copper. By Col. J. T. Smith, Madras Engineers, F. R. S. Proc. Roy. Soc., vol. 23, 1875, pp. 433–435.

Observations made at the Indian mints on the causes which influence the liquation of the coin alloys of silver and copper.

STODART and FARADAY. Experiments on the Alloys of Steel, made with a View to its Improvement. By J. Stodart, F. R. S., and M. Faraday. Quart. Jour. Sci., vol. 9, 1820, pp. 319–330. *Ann. de Chim.*, vol. 16, 1820, pp. 127–144.

——— On the Alloys of Steel. Phil. Trans., 1822, pp. 253–270. *Ann. de Chim.*, vol. 21, 1822, pp. 62–74. Dingler's *Journal*, vol. 8, 1822, p. 252.

STOVER. On the Alloys of Copper and Zinc. By Frank H. Stover. Chemical News, vol. 2, 1860, pp. 303–305; vol. 3, 1861, pp. 22–24, 37–38, 51–53, 70–72, 149–151, 164–166. Memoirs of the American Academy, vol. 8, 1863, pp. 27–56. Erdmann's *Journal*, vol. 72, 1861, pp. 239–242.

Experiments on the crystallization of the alloys of copper and zinc. Stover concludes that all the alloys of copper and zinc are simply isomorphous mixtures of the two metals.

THOMSON. Analysis of a Chinese Gong. By Thomas Thomson. Thomson's Ann. Phil., vol. 2, 1813, pp. 208–210. *Ann. de Chim.*, vol. 87, 1814, pp. 46–53.

Copper, 80.427; tin, 19.573. Remarkable for its high specific gravity—8.953.

——— On Melting Points of Alloys of Lead, Tin, Bismuth, and Zinc. Glasgow Phil. Soc. Proc., vol. 1, 1841–'44, pp. 77–82.

TISSIER. *Note sur les alliages d'aluminium.* Note on the alloys of aluminum. By Chas. and Alex. Tissier. *Comptes Rendus*, vol. 43, 1856, pp. 885, 886. Erdmann's *Journal*, vol. 69, 1856, p. 381. Dingler's *Journal*, vol. 143, 1857, pp. 42–45.

——— *Ueber Metalllegirungen, mit besonderer Berücksichtigung des Aluminiums.* On metallic alloys, with special reference to those of aluminum. Dingler's *Journal*, vol. 166, 1862, p. 427. From the *Technologiste*, April, 1862, p. 348.

TOUCAS. *Silberähnliche Legirung.* Alloy resembling silver. Dingler's *Journal*, vol. 143, 1857, p. 157. British patent, 1856, February 22, No. 459.

Alloy of 4 parts copper, 5 tin, 1 each lead, zinc, and antimony.

TROOST and HAUTEFEUILLE. *Sur les alliages de l'hydrogène avec les métaux.* On the alloys of hydrogen with the metals. By MM. L. Troost and P. Hautefeuille. *Ann. de Chim.*, vol. 2, 1874, pp. 273–288. *Comptes Rendus*, vol. 78, 1874, pp. 807–811.

Describes alloys of hydrogen with sodium, potassium, and palladium.

URE. Ure's Dictionary of Arts, Mines, and Manufactures. Vol. 1, articles on alloys, brass, bronze, &c.

UCHATIUS. Report of experiments made by General Uchatius for the Austrian Government on hardening bronze for cannon. Translated into English, and communicated to the Ordnance Department of the United States, by Col. T. T. S. Laidley, U. S. A. Published as "Ordnance Notes No. XL, Washington, D. C., 1875."

Extraordinary hardening and increase of strength of bronze guns were produced by driving mandrels or plugs into the bore. Some specimens of hardened bronze had a tensile strength of 70,000 pounds per square inch.

VOGEL. *Legirung zu Compositions feilen.* Alloy for composition files. Dingler's *Journal*, vol. 159, 1861, pp. 211, 212.

——— A new Alloy of Copper and Aluminum for Journal Brasses. Scientific American, vol. 4, 1861, p. 311.

VON HAUER. *Ueber die leicht schmelzbaren Kadmium-Legirungen.* On the easily-fusible cadmium alloys. By Carl Ritter von Hauer. Dingler's *Journal*, vol. 176, 1865, p. 371. Erdmann's *Journal*, vol. 94, 1865, pp. 436–439. Phil. Mag., vol. 30, 1865, pp. 447–448.

Vigouroux. *Weisse nicht oxydirbare Metalllegirung für Fasshähne.* White, unoxidizable alloy for facets. Dingler's *Journal*, vol. 178, 1865, p. 242.

Contains tin, antimony, and nickel.

Wade. Reports on Experiments on Metals for Cannon. By officers of the Ordnance Department, United States Army. 1 vol. Philadelphia, 1856.

Contains a valuable report by Major Wade, U. S. A., on the properties of bronze for cannon, with description of the testing apparatus used, effects of sudden cooling, separation of the metals, and discussion of results.

Watt's. Watt's Dictionary of Chemistry. Vol. 3, pp. 942–946. Articles on metals and alloys. See also under heads of the different metals.

Weidemann and **Franz.** *Ueber die Wärme-Leitungsfähigkeit der Metalle.* On the heat conductivity of metals. By G. H. Weidemann and Rudolph Franz. Pogg. *Annalen*, vol. 89, 1853, pp. 497–531. Phil. Mag., vol. 7, 1854, pp. 33–39.

Weidemann. *Ueber die Leitungsfähigkeit einiger Legirungen für Wärme und Elektricität.* On the conductivity of some alloys for heat and electricity. By G. Weidemann. Pogg. *Annalen*, vol. 108, 1859, pp. 393–407. Phil. Mag., vol. 19, 1860, pp. 243, 244.

The order of conductivity of the metals was found to be the same for heat as for electricity.

Weissenborn. Weissenborn's American Locomotive Engineering contains table of useful alloys of copper, including those used in locomotives.

Wertheim. *De l'élasticité et de la ténacité des alliages.* On the elasticity and tenacity of alloys. By M. G. Wertheim. *Comptes Rendus*, vol. 15, 1842, p. 110; vol. 16, 1845, pp. 998–1000.

Experiments upon 54 binary and 9 ternary alloys, with a view to determine whether their elasticity and tenacity followed any general laws.

Wöhler and **Michel.** *Ueber krystallisirte Verbindungen von Aluminium mit Metallen.* On crystallized compounds of aluminum with metals. Liebig's *Annalen*, vol. 115, 1860, pp. 102–105. Phil. Mag., vol. 20, 1860, p. 377. Erdmann's *Journal*, vol. 82, 1861, pp. 237, 238.

Alloys of aluminum with tungsten, molybdenum, manganese, iron, and nickel.

Wood. New fusible metal. Jour. Frank. Inst., vol. 40, 1860, pp. 125–128. Phil. Mag., vol. 20, 1860, p. 403. Dingler's *Journal*, vol. 158, 1860, pp. 376, 377. U. S. patent, March 20, 1860.

Wright. Improvement in alloys of nickel, silver, and copper. U. S. patent. Journal of Applied Chemistry, vol. 8, 1873, p. 158.

RESEARCHES ON THE ELASTICITY AND TENACITY OF THE ALLOYS.

By M. G. Wertheim.*

In the numerous researches which have been undertaken on the mechanical properties of matter, the experimenters have for the most part only confirmed the laws which analysis had already made known, or examined the substances which are used in construction. Thus, while on the one hand the laws which govern slight changes of form and vibrations may be considered as perfectly well understood, and on the other hand, iron, steel, wood, and stone have been carefully studied, the mechanical properties of bodies in general, and the laws which control the displacement of their molecules, when this displacement is no longer very slight compared to the distances which separate them, have been almost wholly neglected.

The constancy or the variability of the coefficient of elasticity in the same substance under different circumstances, the changes that mechanical treatment, annealing, and elevation of temperature can produce, the relation between the theoretical and the actual rapidity of the sound, the laws of permanent displacements, and the different positions of equilibrium, the existence of a certain limit of elasticity and of a maximum elongation, and finally the numerical values of all these quantities, and their relations to the chemical nature of the material,† offer so many questions which have not as yet been discussed by philosophers, or which have been solved in different ways. In this, the first memoir which I have the honor to submit to the judgment of the academy, I discuss only the simple metals. In a short recapitulation of work already accomplished I will mention first the experiments on the constancy of the coefficient of elasticity.

Coulomb and Lagerhjelm have found the same coefficient of elasticity for iron and steel of the same sample, whatever the mechanical treatment to which they were subjected; M. Poncelet, on the contrary, relying on the uniformity of known results, does not admit this constancy even for iron. The other metals have not yet been studied in this respect. M. Gerstner concludes from his experiments on steel bars, that the coefficients of elasticity remain the same in the different positions of equilibrium of the bar.

Passing over the differences which may be exhibited in the same metal on account of the variations in its density or because of its impurity, the coefficients of elasticity have been determined for lead, zinc, silver, platinum, copper, iron, and steel, by Coulomb, Barlow, Tredgold, Young, Rennie, Duleau, Navier, Lagerhjelm, Leslie, Gerstner, Sequin, Martin, Savart, Weber, Ardant, and by the royal commission of Hanover.

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* *Comptes Rendus*, vol. 15, 1842, p. 110.

† Some months after the deposition of my packet, M. Masson presented to the academy a paper in which he seeks to establish by his own experiments on iron, copper, and zinc, and by the experiments of Chladni on tin and silver, the following law: Multiplying the coefficients of elasticity of the simple bodies by a multiple or submultiple of their equivalents, a constant number is obtained. M. Masson himself attributes this fact only to accident (*Annales de Chimie et de Physique*, 3^{me} série, t. iii). I have not therefore considered it necessary to repeat the above. It will be understood, further, that a certain agreement can always be obtained by choosing arbitrarily the whole numbers by which the atomic weights must be multiplied or divided.

Chladni took the rapidity of sound on iron, copper, silver, and tin, and Savart on iron, steel, and copper. M. Masson made known the rapidities in zinc and lead.

These results form almost the whole of our experimental knowledge of elasticity in an ordinary temperature; the variations in elasticity caused by the elevation of the temperature have not yet been investigated.

The researches on the cohesion of the metals are much more numerous, but from their nature also less apt to give concordant results. It would take too long to repeat them here. I will only say further, that the influence of annealing on cohesion has been investigated by MM. Dufour, Baudrimont, and Karmarsch, and that of elevation of temperature upon the cohesion of iron by MM. Tredgold, Lagerhjelm, Trémery, Poirier, and Dufour. Finally, MM. Minard and Desormes have made known the diminution of cohesion produced by heat in lead, tin, and copper. My experiments have been on the homogeneous metals which I have myself reduced or analyzed, when it was impossible to obtain them perfectly pure; these were lead, tin, cadmium, gold, silver, zinc, platinum, copper, iron, and steel. Each metal was first melted, when possible, then rolled and drawn, and finally annealed. In each of these conditions its density was noted; then I determined its coefficient of elasticity and the rapidity of sound, by means of three different methods: by transverse vibrations, by longitudinal vibrations, and by elongation.

The number of transverse vibrations per second was determined by the method of sketching the vibrations, original with M. Duhamel. A little elastic bent wire attached to the top of the rod under examination left an impression upon a disk coated with lampblack. Having failed to give this disk a uniform rate of motion, I determined the length of the vibrations by comparing the vibrations of the rod with those of a standard fork made by M. Marloye, and making exactly 256 vibrations per second; the time was thus determined within at least $\frac{1}{2560}$ of a second.

The number of longitudinal vibrations was determined by means of a differential sonometer consonant with the same fork. I satisfied myself as to the exactitude of estimates by calculating directly the longitudinal vibrations drawn by two rods of two meters length. The difference was only between three and seven vibrations in a thousand. Finally, these rods and bars were submitted to the action of successively increasing loads in an apparatus which allowed of even quite heavy loads being put on or taken off with facility and without jar.

The total elongations (sets) were of two kinds, one which disappears with the removal of the charge, and another which is permanent. Each of these two parts was measured separately, by means of a cathetometer measuring hundredths of a millimeter. Thus, not only the coefficient of elasticity was determined anew in each position of equilibrium that the rod attained, but also all that relates to the limit of elasticity, to the maximum of elongation, and to cohesion, was studied at the same time. After rupture, the density and elasticity of the fragments were examined anew, and, finally, all the experiments in elongation were repeated at the temperatures of 100° and 200° C. These, then, are the conclusions that may be drawn from these experiments.

1st. The coefficient of elasticity is not constant for the same metal; whatever augments the density increases it, and reciprocally.

2d. The longitudinal and transverse vibrations evidently give the same coefficient of elasticity.

3d. The vibrations give coefficients of elasticity much greater than those obtained by elongation. This difference is due to the acceleration of movement produced by liberated heat.

4th. Consequently, sound in solid bodies is due to waves and condensation, and we may be able by means of the formula given by Mr. Duhamel to make use of the relation between actual and theoretical speeds of sound, to find out the relation of specific heat under constant pressure to that at constant volume. This ratio is greater for annealed than for non-annealed metals.

5th. The coefficient of elasticity diminishes with the elevation of the temperature at a more rapid rate than that which is due to the corresponding dilation.

6th. Magnetization does not sensibly change the elasticity of iron.

7th. The elongation of rods and bars by the application of loads affects their densities very slightly. The coefficient of elasticity should therefore vary as little in the different positions of equilibrium; and this is in fact what takes place, in so far as the loads do not become great enough to produce rupture. The law of Gerstner is therefore confirmed by all the metals of which the particles take a position of equilibrium after having passed their limit of elasticity.

8th. The permanent alloys are not found intermittently, but in a continuous manner. By suitably limiting the load and its duration of action, such permanent elongation as may be desired can be produced.

9th. No true limit of elasticity exists; and if no permanent elongation is observed for the first loads, it must be because they have not been allowed time to act, and because the rod submitted to the experiment is too short relatively to the delicacy of the measuring instrument.

The values of maximum elongation and cohesion also depend much on the manner of operation. They become greater the more slowly the loads are increased. It may be seen from this how arbitrary is the determination of least and of greatest permanent elongation, and that we cannot, with Lagerhjelm found a law upon their values.

10th. The resistance to rupture is considerably diminished by annealing. The elevation of the temperature even to 200° C. does not greatly diminish the cohesion of metals previously annealed.

After this purely experimental part, I sought to discover a relation between the coefficient of elasticity, which is the only truly scientific mechanical datum, and the molecular constitution for comparing the result of calculation with those of experiment.

M. Poisson has been led to the following expression of the coefficient of elasticity:

$$q=\frac{\pi}{g}\sum_{r=x}^{r=\infty}\frac{r^5}{a^5}\,\frac{d\,\frac{1}{r}fr}{dr},$$

in which *a* is the mean distance of the molecules, *r* the radius of action of the molecule, the function *fr* giving the result of simultaneous action of the attractive molecular force and of the repulsion due to heat.

To find *a* I assume that the weight of each molecule is expressed by its atomic weight. We know that this hypothesis is probable from the researches of MM. Dulong and Petit, Avogrado, Regnault, and Baudrimont, on specific heat.

The relative number of atoms contained in the same volume is then obtained by dividing the specific weight by the atomic weight; the reciprocal of the cube root of this number is the measure of the distance of the molecules for each metal in its different conditions—that is to say, the value of a.

There remains, then, in the formula to be determined, only the functions fr which we may attempt to deduce.

The following are the results of this formula:

1st. q should become greater when a diminishes, and reciprocally. It may be seen in the fourth table of my memoir that this really takes place, but the condensations and dilatations that we can produce by these mechanical means are too slight for us to determine with certainty the relation between the changes of a and q; nevertheless, the product qa^7 is very nearly constant for the same metal. With elevation of temperature the coefficient of elasticity diminishes so rapidly that the product qa^7 is always less than at an ordinary temperature; the function fr should then include temperature.

2d. The different metals follow in the same order in proximity of the molecules, in their coefficient of elasticity, and in their power to conduct sound in proportion to its intensity (this last is only approximately known by the experiments of Perolle). Platinum only ranks between copper and iron in relation to the coefficient of elasticity, while it ranks between zinc and copper in relation to the distances of the molecules.

3d. The product of the coefficient of elasticity by the seventh power of the mean relative distance of the molecules is the same for the greater part of the metals. This agreement is so complete that it can be exacted to this degree of approximation for lead, cadmium, gold, silver, zinc, and iron; but copper gives a somewhat smaller product, and tin and platinum much higher products, than the other metals. If this agreement were general, we might infer from it that the resultant of the attractive molecular force and heat repulsion diminishes in the inverse ratio of the fifth power of the distances. But this agreement is not confirmed by all the metals experimented upon, proving only that this resultant diminishes in fact, as we assume to be the case in our calculations, much more rapidly than in the inverse ratio of the square of distances. In the letter attached to this memoir the author requests the opening of a sealed packet dated July 19, 1841. This packet, opened on the spot, contained the following note: "Sealed packet addressed by M. Wertheim in 1841, accepted by the academy at the session of July 9"

Philosophers generally admit that atomic weights represent the true weight of the molecules, and that the diameters of the molecules are variable in their ratio to the distances which separate them. We can then obtain the number of molecules of the different simple bodies contained in the unit of volume by dividing their specific weights by their atomic weights; as to composite bodies, this same reasoning will lead to a knowledge of their molecular arrangement. Now the attractive force should necessarily be a function of the distance, a function that experiment alone can make known, and which leads to the knowledge of the laws of cohesion, of elasticity, and of the rapidity of sound.

The comparison contained in the following table, which I communicated to M. d'Estinghausen, at Vienna, four years since, shows the intimate relation of these different quantities. The first column contains the specific weights of the melted metals; the second the atomic weights, calling the atomic weight of oxygen=1; the third column contains the number of atoms in the unit of volume.

The atomic weights are those of M. Berzélius, except that of silver, which is reduced one-half, conformably to the researches of MM. Dulong and Petit, and of M. Regnault, on specific heat.

	S.	A.	S. A.	Resistance to rupture per millimeter.		Coefficient of elasticity, Tredgold.	Rapidity of sound, Chladni.
				By extension after Guyt-Morveau.	By compression after Rennie.		
Lead	11.352	12.94498	0.8769	0.022	1.45	600	....
Tin	7.285	7.35294	0.9907	0.003	6.20	3.200	7.5
Gold	19.258	12.43013	1.5493	0.274	....	....	....
Silver	10 542	6.75803	1.5599	0.341	....	....	9.0
Zinc	6.861	4.03226	1.7015	*0.199	....	9.600	....
Platinum	21.530	12.33499	1.7454	0.499	....	....	....
Copper	8.850	3.95695	2 2365	0.550	38.55	....	12.0
Iron	7.788	3.39205	2.2959	1.000	....	20.000	17.0

* The resistance of zinc is lower, which should not be according to its number of atoms; but this disagreement may reasonably be attributed to the impurity of the metal experimented upon or to its crystallized condition.

Notice further, that the metals range as to their conductibility for the intensity of sound, according to Perolle: lead, tin, gold, silver, copper, iron.

Lastly, the diamond, hardest of the simple bodies, contains nearly as many molecules as iron; its number is 4,668 to 4,708; these numbers are obtained by dividing its extreme specific weights, 3501–3531, by its atomic weight, 75, recently determined by M. Dumas.

We see that in the simple bodies which have been submitted to experiment thus far, cohesion, elasticity, and conductibility of sound, as much with regard to its quickness as to its intensity, are as much greater as the molecules of the same bodies are nearer to one another at the same temperature.

But the experiments are far from being sufficiently exact to serve as a basis for calculations. In fact only a small number of chemically impure metals have been tested by the methods of extension and of rupture, which seem to me better adapted to researches on vibrations than to the study of molecular forces. It was with this view that I made the experiments in vibrations of bars of chemically-pure metals, the results of which I have the honor to submit to the Academy.

ON THE ELASTICITY AND TENACITY OF THE ALLOYS.

BY M. G. WERTHEIM.*

(Abstract by the author.)

In a previous work which I had the honor to present to the Academy during the session of July 18, 1842, I considered the mechanical properties of the simple metals. After having examined and compared the different methods of studying elasticity in relation to ordinary as well as to high temperatures, I applied these methods to the pure metals and obtained results of which I will describe only those which serve as the basis of the new work.

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* *Comptes Rendus*, vol. 16, 1845, pp. 978–1000.

It was shown by these experiments—

1st. That the coefficient of elasticity is not constant for the same metal, but that it changes with the density and in the same way.

2d. That the longitudinal and transverse vibrations produce a coefficient of elasticity a little greater than that deduced direct by elongation.

3d. That experiment agrees with analysis as to the relation which should exist between the coefficient of elasticity and the mean distance of the molecules; that is, whenever in the same metal this distance becomes greater the coefficient of elasticity diminishes, and reciprocally; consequently the different metals form the same series whether arranged according to their coefficients of elasticity, or according to the proximity of their molecules.

4th. That the product of the coefficient of elasticity by the seventh power of the mean relative distances of the molecules is the same for the greater part of the metals.

In this second paper which I have the honor to present to the Academy, my object is to see, first, if these laws are equally applicable to alloys. Then to ascertain whether the mechanical properties can assist us to an understanding of the arrangement of the molecules of the constituent metals of the alloys; and, finally, to seek for some relations between the properties of the alloys and those of the constituent metals.

In general, the alloys, in spite of their frequent employment in the arts, have not yet been studied as to their elasticity. The coefficients of elasticity of two alloys alone, that of brass and that of bell-metal, have been determined by Tredgold, Savart, Bevan, and Ardant.

The cohesion of the alloys, on the contrary, has been the object of a long series of experiments, especially on the part of Musschembroek and Karmasch, but yet no general law has been found. The alloys which I have used in my experiments have been prepared in part of the pure metals employed in my former researches, and in part of the purest metals of commerce. After mixing them well, I stirred them frequently while in fusion, then poured them. The ductile alloys were drawn, the others filed to the requisite size. I will not go into the details of these experiments, which were precisely similar to those made on simple metals, but only say that I feel bound to analyze chemically all the alloys, although I might have, for the most part, mixed the metals by atomic weights, or the simple multiples of those weights. But the unequal oxidization or the partial vaporization of a constituent has often and considerably changed the proportions.

When the alloys were composed of metals whose specific weights were very different, or when they offered inequalities of color or of malleability, I made the analysis on parts taken from the two extremities of the cast bar; consequently, with these analyses, I was obliged to reject a large number of non-homogeneous bars.

My experiments were made upon fifty-four binary alloys and nine ternary alloys, among which are found also most of the alloys employed in the arts, such as brass, pinchbeck, gong-metal annealed and unannealed, bronze, packfong, type-metal, &c.

These experiments gave the following results:

1st. If we suppose all the molecules of an alloy to be the same distance from one another, as seems natural, we find that the smaller the mean distance the greater is the coefficient of elasticity. We notice frequently some exceptions in the series of alloys, and further, the product qa^7 which is almost constant for simple metals, varies greatly in the alloys. It is possible that another hypothesis on the molecular arrangement will cause this objection to disappear.

2d. The coefficient of elasticity of the alloys agrees sufficiently well with the mean of the coefficient of elasticity of the constituent metals, some alloys of zinc and copper being the only exceptions. The only condensations and expansions which occur during the formation of the alloy do not sensibly affect the coefficient. We can then calculate beforehand what should be the composition of an alloy in order that it may have a given elasticity, or that it may conduct sound with a given rapidity, provided that this elasticity or this velocity fall within the limits of the values of these same quantities for the known metals.

3d. Neither the tenacity, nor the limit of elasticity, nor the maximum elongation of an alloy can be determined *a priori* by means of the same quantities as determined for the metals which compose them.

4th. The alloys act like the simple metals as to longitudinal and transverse vibrations, as well as elongation.

RESEARCHES ON THE METALLIC ALLOYS.

BY M. ALFRED RICHE.*

There is no study more generally neglected than that of the metallic alloys. This very general neglect is due to the fact that the characteristics upon which we rely in determining the purity of substances are usually inapplicable to these substances. The melting points, even, cannot be determined, either because decomposition takes place before they attain their high temperature, or because we have no precise means for determining such high temperatures.

In the second place their crystalline form is not a gauge of their purity, for Cooke and Matthiessen and De Bose have recently shown that the crystalline form of certain alloys does not vary even when 16 per cent. of one of the two metals is substituted for 16 per cent. of the other.

Finally, liquation often prevents the precise determination of the point at which the metal melts and solidifies. This latter property, however, enabled M. Rudberg to prove the existence of true chemical combinations among the numerous alloys of the two metals, but it can only be utilized in a few cases where the point to be determined is that of the melting of alloys at low temperature. There is another characteristic of which we take advantage in other cases, especially when we wish to determine the combinations that water forms with the mineral acids; this is the maximum contraction.

It seems to me that this should be a characteristic of all the metals, but there exists to my knowledge, at least, no data on the subject. It is only known that certain alloys are more dense really than they are theoretically, and that in others, on the contrary, the density given by experiment is less than the average density of the constituent metals.

I. *Alloys of tin and lead.*

Density of the melted tin employed	7.30
Density of the melted lead employed	11.364

The following table, of which the first column contains the theoretical density of the alloys, the second their density as given by experiment, and the third the difference between these two densities, shows that there is sometimes dilatation and sometimes contraction, and that the maximum of contraction corresponds exactly to the alloy Sn^2 Pb:

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* *Comptes Rendus*, vol. 55, 1862, pp. 143–147.

[The sign — indicates dilatation; the sign + indicates contraction.]

	Theoretical.	Experimental.	Difference.
	Density.	Density.	
Sn^5 Pb	8.047	8.046	—0.001
Sn^4 Pb	8.193	8.195	+0.002
Sn^7 Pb^2	8.289	8.2915	+0.0025
Sn^3 Pb	8.407	8.414	+0.007
Sn^5 Pb^2	8.562	8.565	+0.003
Sn^2 Pb	8.764	6.7062	+0.0022
Sn^3 Pb^2	9.044	9.046	+0.002
Sn Pb	9.455	9.451	—0.004
Sn Pb^2	10.115	10.110	—0.005
Sn Pb^3	10.437	10.419	—0.018

The differences being slight I made a large number of determinations, especially on the alloy Sn^3 Pb and those near it; it is for this reason that I took the density of the alloys corresponding to the formulæ Sn^7 Pb^2 and Sn^5 Pb^2.

For the alloy Sn^3 Pb alone I made seventeen determinations, which all gave numbers varying between 8,417 and 8,411. I worked each time upon newly prepared samples in quantities varying between 45 and 75 grammes at varying temperatures.

The alloys were prepared directly by melting in earthen crucibles, stirring carefully, then cooling in a long and narrow cast-iron ingot mold of such shape that solidification took place almost instantly, and consequently liquation did not affect the product obtained.

The density of the entire ingot, and not of a portion of it, was taken. The hydrostatic balance was employed. The numbers obtained correspond to the temperature of 18° C. Analysis of the alloy Sn^3 Pb and ot the alloys near it was afterwards made, and the numbers given by experiment correspond with the theoretical.

Is the alloy Sn^3 Pb a distinct chemical compound? It seems to me unquestionable, for this is the point of saturation, the point of maximum contraction, and this point corresponds to an atomic combination.

Besides—and it is for this reason that I commenced my researches on the alloys of tin and lead which were the principal subject of the works of M. Rudberg—this alloy is the only chemical compound which he admits to exist between these two metals. Two different methods, then, lead to the same conclusion:

II. *Alloys of lead and bismuth.*

Density of the lead	11.364
Density of the bismuth	9.830

	Theoretical.	Experimental.	Difference.	Remarks.
	Density.	Density.		
Bi^2 Pb	10.099	10.232	+0.133	
Bi Pb	10.288	10.519	+0.231	
Bi Pb^2	10.536	10.931	+0.395	
Bi^2 Pb^5	10.622	11.038	+0.416	
Bi Pb^3	10.448	11.108	+0.660	Maximum contraction.
Bi^2 Pb^7	10.748	11.166	+0.418	
Bi Pb^4	10.797	11.194	+0.397	
Bi Pb^5	10.874	11.209	+0.335	
Bi Pb^6	10.932	11.225	+0.293	
Bi Pb^7	10.979	11.235	+0.254	

The maximum contraction, then, corresponds to the alloy Bi Pb^3, and on the other side of this alloy a very regular diminution in contraction will be noticed. The differences being very great both between the theoretical and experimental density, and between the density of each alloy and that of its neighbors, I only made two determinations for each alloy. As analysis of the ends and of the middle of the ingot formed by the alloy Bi Pb^3 gave the same numbers, it seems to me that this alloy should be considered as a chemical compound.

M. Rudberg did not experiment upon this alloy Bi Pb^3, which is of a grayish-white, and formed entirely of little crystals. Distilled water attacks it with sufficient rapidity to give birth to little pearly-white spangles, which are held in suspension in this liquid when it is stirred.

III. *Alloys of antimony and lead.*

Density of the antimony.. 6.641
Density of the lead.. 12.364

	Theoretical.	Experimental.	Difference.	Remarks.
	Density.	Density.		
Sb^4 Pb	7.237	7.214	—.023	
Sb^3 Pb	7.385	7.361	—.024	
Sb^2 Pb	7.651	7.622	—.029	
Sb Pb	8.271	8.233	—.038	
Sb Pb^2	9.046	8.999	—.047	Maximum dilatation.
Sb Pb^3	9.510	9.502	—.008	
Sb Pb^4	9.819	9.817	—.002	
Sb Pb^5	10.040	10.040	Nulle.	
Sb Pb^6	10.206	10.211	+.005	
Sb Pb^7	10.335	10.344	+.009	
Sb Pb^8	10.438	10.455	+.017	
Sb Pb^9	10.521	10.541	+.020	
Sb Pb^{10}	10.592	10.615	+.023	Maximum contraction.
Sb Pb^{11}	10.652	10.673	+.021	
Sb Pb^{12}	10.702	10.722	+.020	
Sb Pb^{13}	10.746	10.764	+.018	
Sb Pb^{14}	10.785	10.802	+.017	

The maximum of contraction corresponds moreover to an atomic alloy Sb Pb^{10}, which has a rather simple composition, and near the alloy Sb Pb^2 is the maximum of dilatation. The phenomena are therefore more complicated than in the preceding cases.

These alloys are crystalline. The alloys near Sb Pb^2 crystallize in quite large scales. The crystals of the following are very fine yet very distinct:

IV. *Alloys of tin and bismuth.*

I have been able to make but one series of experiments on pure bismuth. I propose to prepare some anew in order to verify them.

	Theoretical.	Experimental.	Difference.	Remarks.
	Density.	Density.		
Bi^2 Sn	9.426	9.434	+.008	
Bi Sn	9.135	9.145	+.010	
Bi Sn^2	8.740	8.754	+.014	
Bi Sn^3	8.491	8.506	+.015	
Bi Sn^4	8.306	8.327	+.021	
Bi Sn^5	8.174	8.199	+.025	Maximum contraction.
Bi Sn^6	8.073	8.097	+.024	
Bi Sn^7	7.994	8.017	+.023	

The maximum of contraction, therefore, should take place in the alloy Bi Sn^5 which is a silvery-white metal formed of little crystalline grains commingled. This alloy was not attacked by distilled water; at the end of several hours it retained its brilliancy and its silvery luster.

RESEARCHES ON THE ALLOYS.

By M. Alfred Riche.*

In this note, which is a summary of a general research on the alloys, I have to do only with the alloys of copper and tin with respect to their density, liquation, and fusibility.

Density.—The first determinations were made on bars weighing from 50 to 60 grammes, but no great importance can be attached to the results obtained on account of the considerable variations which exist in the texture of the different alloys, and for this reason I afterward worked with these materials reduced to fine powder. The subjoined table shows a new fact, namely, that the contraction increases quite regularly from the alloys very rich in tin, up to the alloy $Sn\,Cu^2$, and that from this point it suddenly increases, attaining a maximum when the tin and copper are in the relation of 1: 3. From this alloy the density diminishes, then again increases quite regularly, but the density of the alloys containing most copper is less than that of the alloy $Sn\,Cu^3$, which contains only 62 per cent. of copper. Besides, this alloy is clearly different from all the others in its characteristics; it is brittle enough to be pounded in a mortar, and is seen in bluish crystalline grains, which in no respect resemble tin or copper.

Density of the alloys of copper and tin.

Formula of the alloy.	Centesimal composition.	Density of the bars.	Density of the powders.		Calculated density.	Difference.
$Sn^5\,Cu$	Sn....90. 27 Cu.... 9. 73	7. 52	7. 23 7. 82	7. 28	7. 43	—0. 15
$Sn^4\,Cu$	Sn....88. 16 Cu....11. 84	7. 50	7. 04 7. 58	7. 31	7. 46	—0. 51
$Sn^3\,Cu$	Sn....84. 79 Cu....15. 21	7. 53	7. 43 7. 44	7. 44	7. 50	- 0. 06
$Sn^2\,Cu$	Sn....78. 79 Cu....21. 21	7. 74	7. 81 7. 84	7. 83	7. 58	+0. 25
$Sn\,Cu$	Sn....65. 01 Cu....34. 99	8. 12	7. 93 7. 87	7. 90	7. 79	+0. 11
$Sn^2\,Cu^3$	Sn....55. 33 Cu....44. 67	8. 30	8. 00 8. 11	8. 06	7. 93	+0. 13
$Sn\,Cu^2$	Sn....48. 16 Cu....51. 84	8. 57	8. 07 8. 23	8. 15	8. 04	+0. 11
$Sn\,Cu^3$	Sn....38. 21 Cu....61. 79	8. 96	8. 86–8. 84–8. 99 8. 93–8. 92–8. 90	8. 91	8. 21	+0. 70
$Sn\,Cu^4$	Sn... 31. 72 Cu....68. 28	8. 80	8. 65–8. 85 8. 80	8. 77	8. 32	+0. 45
$Sn\,Cu^5$	Sn....27. 09 Cu....72. 01	8 87	8. 73–8. 59 8. 51–8. 65	8. 62	8. 40	+0. 22
$Sn\,Cu^6$	Sn... 23. 69 Cu... 76. 31	8. 91	8. 54 8. 77	8. 65	8. 46	+0. 19
$Sn\,Cu^7$	Sn....20. 98 Cu....79. 02	8. 90	8. 67 8. 77	8. 72	8. 50	+0. 22
$Sn\,Cu^8$	Sn....18. 85 Cu... 81. 15	8. 86	9. 06–8. 62 8. 83	8. 84	8. 54	+0. 30
$Sn\,Cu^{10}$	Sn....15. 67 Cu... 84. 33	8. 83	8. 72–9. 04 8. 98–8. 73	8. 87	8. 60	+0. 27
$Sn\,Cu^{15}$, cannon-bronze	Sn....11. 00 Cu....89. 00	8. 80	8. 97–8. 74 8. 81	8. 84	8. 69	+0. 15

Liquation.—The separation of the alloys into other alloys at the moment of solidification is not as marked as that of the alloys of silver and copper. In order to show this characteristic, the material must be stirred at the moment of solidification in order to separate the little drops of metal from the crystals already formed.

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[*] *Annales de Chimie*, vol. 30, 1873, pp. 351-419; Dingler's *Journal*, vols. 213, 214; 1874.

The following results were obtained on the last sample left liquid in a mass weighing 1,000 to 1,200 grammes:

Formula of the alloy.	Calculated weight of tin.	Weight of tin as found.	Formula of the alloy.	Calculated weight of tin.	Weight of tin as found.
$Sn^5 Cu$	90.27	98.50	$Sn Cu^5$	27.09	27.76
$Sn^3 Cu$	84.79	96.99	$Sn Cu^6$	23.69	25.17
$Sn^2 Cu$	78.79	94.40	$Sn Cu^7$	19.98	24.85
Sn Cu	65.01	82.83	$Sn Cu^8$	18.85	24.62
$Sn Cu^2$	46.49	50.42	$Sn Cu^{10}$	15.67	24 50
$Sn Cu^3$	37.37	37.29	$Sn Cu^{15}$	11.00	14.35
$Sn Cu^4$	31.72	31.15			

Consequently, liquation is exhibited by all the alloys except $Sn Cu^3$ and $Sn Cu^4$.

Fusibility.—In order to determine the fusibility of the alloys, I have recourse to the thermo-electric couple of platinum and palladium of M. Becquerel. This apparatus was made by M. Ruhmkorff. It may render great service to chemists, and is already employed in the metal foundery and in the pottery manufactory; but instead of using an ordinary galvanometer, I employed Weber's needle, which is much more sensitive.

I worked ordinarily on the preceding alloys and on the metals of which the points of fusion and of ebullition have been taken as fixed points by various experimenters.

From the numerous determinations that I made, it follows that the solidification of the alloys $Sn Cu^3$ and $Sn Cu^4$ took place at a temperature intermediate between the point of fusion of antimony and the boiling point of cadmium.

Boiling water under a pressure of 76 centimeters	24
Solidification of tin	57
Solidification of antimony	206
Solidification of $Sn Cu^3$	247
Solidification of $Sn Cu^4$	265
Ebullition of cadmium	335

I tried this determination on all the preceding alloys, and will give the results in the detailed memoir; but it is clear that, on account of liquation, we can obtain an exact result only with the alloys $Sn Cu^3$ and $Sn Cu^4$, in which there is no sensible liquation.

In a previous paper I gave the fusibility and density of the bronzes, and I showed that the alloy $Sn Cu^3$ does not separate into other compounds even when it is kept melted and stirred for a long time. I stated, as Calvert and Johnson had previously shown, that copper and tin exhibit maximum contraction in this alloy, contrary to the opinion of other experimenters, who have maintained that contraction increases with the proportion of tin.*

The errors on this point and the differences which exist between the numbers obtained by Calvert and Johnson and mine are probably due to the fact that I worked on alloys reduced to fine powders, while the other experimenters, and probably the able English authorities themselves, made use of ingot metal. Now, supposing that they avoided the formation of blowholes in cooling, the texture of the alloys presents such differences, and the density of certain bronzes varies so greatly with the rapidity of cooling, that the materials cannot be compared if plates or ingots are employed.

I. Caron, in his celebrated researches on steel, has undoubtedly proved that tempering diminishes the density of this body. It is said that the same is true of the bronze of sonorous instruments.† My experiments, recapitulated in the following table, show the contrary.

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* Briche, *Traité de Chimie de M. Dumas*, t. iii, p. 512.

† Dussaussoy, *Traité de Chimie de M. Dumas*, t. iii, p. 517. Wertheim, *Annales de Chim. et de Phys.*, 3d série, t. xii, p. 593.

Then, tempering and annealing produce entirely different effects upon steel and upon bronze; while tempering diminishes the density of the former, it increases the density of the latter. The fact is no more than natural, for tempering hardens wrought steel, while it softens bronze. As to annealing, it increases the density of tempered steel, while it diminishes the density of tempered bronze.

Huntsmann steel used in making coin at the mint of Paris.

Number of order.	Density of cast bars.	Density after annealing.	Density after tempering.	Density after annealing and tempering.	Density after tempering and annealing.
1	7.841	7.843	....	7.758	....
2	7.841	7.843	....	7.755	....
3	7.839	7.845	....	7.763	....
4	7.839	7.842	....	7.705	....
5	7.839	....	7.735	....	7.831
6	7.846	....	7.749	....	7.833
7	7.839	....	7.738	....	7.828

Bronze at 20 per cent. (sonorous instruments).

Number of order.	Density after casting.	Density after tempering.	Density after annealing.	Density after tempering and annealing.	Density after annealing and tempering.	Density after tempering, annealing, and second tempering.	Density after annealing, tempering, and second annealing.	Density after 2 annealings and 2 temperings.	Density after 2 annealings, 2 temperings, and a third annealing.
1	8.787	8.823	....	8.817	....	8.849	....	....	....
2	8.858	8.915	....	8.907	....	8.927	....	....	....
3	8.826	8.863	....	8.847	....	8.874	....	....	....
4	8.862	8.706	....	8.886	....	8.907	....	....	....
5	8.863	8.906	....	8.894	....	8.922	....	....	....
6	8.737	....	8.733	....	8.763	....	8.753	8.775	8.786
7	8.873	....	8.782	....	8.911	....	8.889	8.926	8.927

II. In view of these results, it will be interesting to know whether these differences are shown when the materials are subjected to hammering or to the press. The following table shows the variations in density when steel and bronze are subjected to the successive action of blow and of heat:*

	Steel.		Bronze.	
	I.	II.	Tempering.	Annealing.
Initial density	7.845	7.847	8.527	8.660
Density after action of fire	7.849	7.849	8.543	8.653
Density after first blow	7.839	7.843	8.771	8.738
Density after second action of fire	7.844	7.843	8.777	8.790
Density after second blow	7.838	7.839	8.871	8.633
Density after third action of fire	7.844	7.845	8.877	....
Density after third blow	7.837	7.841	8.918	....
Density after fourth action of fire	7.849	7.854	8.927	....
Density after fourth blow	7.849	7.849	8.937	....
Density after fifth action of fire	7.844	7.845	8.945	....

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* These metals were in sheets weighing from 80 to 150 grammes. They were struck under a press worked by four men. The steel had been annealed. The bronze had been tempered in some experiments and annealed in others. The materials were placed in the same sheet-iron case, surrounded with coal dust.

Hence, blows act very differently on bronze and on steel. They considerably increase the density of the former, while they produce scarcely any sensible difference in steel, though the tendency is to diminish its density. If this latter effect is realized in all the conditions of the blow for steel, we may conclude that the blow produces in these two cases the same result as tempering. The fact is unquestionable for bronze at least; and as in this case the action of heat and of blows tend both in the same direction, the density increases considerably; indeed, after five temperings the density increased nearly one-twentieth.

We see, then, how on the one hand a block of steel subjected to impression in making coin undergoes thirty and even sixty annealings without being affected; and we see on the other hand how all the attempts made in our country to manufacture tamtams and cymbals with the metal of the Chinese and Turks have been unsuccessful, for the metal once melted it was made red-hot or tempered, and then worked *cold;*[*] all operations which contract the metal, and make it liable to fracture during the working.

In order to succeed, the Oriental method of working must be exactly followed. Now, we understand this method perfectly, thanks to various travelers, and especially to M. Champion, of the *Conservatoire des Arts et Metiers*, who describes the operation in all its details in a work which will shortly be published. This method is very reasonable. Every part of the work which has for its object the thinning of the cast metal is done by rapid hammering at a high temperature. The dilatation produced by heat counterbalances the contraction caused by the hammering.

III. Copper subjected to successive tempering and annealing presents nothing similar. The density scarcely varies. It falls a little, for after seven operations it was reduced from 8.921 to 8.781. No marked difference can be observed in the effect of tempering and annealing. It is the same for the bronzes containing but little tin.

If in making copper medals, the medal still *red-hot* be plunged into acidulated water, it is simply to avoid the considerable oxidization produced by slow cooling in contact with air.

I had some copper medals struck, and determined the density after each compression and after each cooling. I found that after six operations the density had again become what it was after casting. This peculiarity and the softness of the copper make this metal one especially adapted to making medals.

Analyses of antique medals show that the ancients sometimes employed copper for this purpose, but generally bronze, and that the proportion of tin varied between one and twenty per cent.

After having discovered, by means of an ingenious apparatus made by M. Magna, that bronzes containing two to four per cent. of tin are not much harder than copper, I had some medals of copper and of other alloys struck, without any difference in the mode of working. The differences were not very noticeable for medals of 35 millimeters and under, but became very marked in strips of 50 and 68 centimeters.

While in making a medal the copper had to undergo but 7 compressions and 7 annealings, there were required 10 for bronze of 97 of copper and 3 of tin; 12 for bronze of 96 of copper and 3.5 of tin; 13 to 14 for bronze of 96 of copper and 4 of tin; 16 at least for bronze of 95 of copper and 5 of tin.

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[*] We read, it is true, in several works on chemistry, that this method is satisfactory. Our best manufacturers, M. Lecomte and M. Gautrot, assured me that no one had yet succeeded in making tamtams and cymbals with the metal of the Orientals. (C. R., 1869, Semestre, t. lxix, No. 5.)

The introduction of zinc softens the metal slightly, for 14 compressions were sufficient to make the same medal with an alloy containg 95 copper, 4 tin, 1 zinc, and 16 to 18 were necessary with an alloy containing 94 copper, 4 tin, and 2 zinc, which was formerly employed.

Very important works on the alloys have been published within a few years by MM. Wertheim, Levol, Matthiessen, Calvert and Johnson, &c. Yet we are far from understanding satisfactorily the general properties of the more important classes of these bodies, such as bronze and brass, and I have devoted myself to filling up some of the gaps in our knowledge of these subjects. In this first paper I consider more especially the alloys of copper and tin with reference to their fusibility, liquation, and the modifications which take place in their volume, under the influences of annealing, heating, and mechanical action. Afterwards, I speak more briefly of copper, of its alloys with zinc, aluminium, nickel, and iron, and finally I compare these bodies with steel, iron, and glass, with reference to the variation in volume that tempering and annealing produce in these different substances.

The determination of the mechanical properties remained to be considered. Not having at my disposal the necessary apparatus, I applied to M. Tresca, who has established at the "*Conservatoire des Arts et Metiers*" special apparatus for this sort of experiments, and I shall shortly publish, in common with M. Alfred Tresca, the second part of this work, including the study of the mechanical properties of copper, tin, zinc, and their principal alloys, prepared in atomic proportions.

§ I.—FUSIBILITY OF SOME METALS AND ALLOYS.

Liquation of bronze.

I have tried various means to determine the fusibility of metals which melt at high temperatures, and it seems to me that only one can be practically applied and furnish sufficiently exact results; this is the thermo-electric pyrometer, formed by the junction of a wire of platinum and one of palladium (an apparatus proposed in 1835 by M. Becquerel, senior, and carefully considered by M. Edmond Becquerel in 1863).

This instrument allows of the temperature being measured by comparing the deviation produced at the moment when the matter solidifies or melts, with the deviation observed in baths having a fixed temperature. This pyrometer, so graduated, may be of great service in chemical and industrial pursuits. M. Rubmkorff, who makes these instruments, has introduced them into the establishments of the founders and pottery manufacturers.

The needle employed in manufactures is an ordinary one, but for researches, where precision is required, it is necessary to make use of Weber's, which I have employed. The only difficulty—and it is a very serious one—is in finding a position for it where it will not shake or tremble.

I use at least one kilogram of alloy. When it is fusible at a low temperature it is heated in a crucible in which the porcelain tube containing the pyrometer is placed. When it melts at a high temperature it is first raised to that point in a blast-furnace, and the crucible of molten metal is placed in an ordinary laboratory furnace where it is slowly cooled. The pyrometric tube previously heated is then introduced into the bath, and the deviation at the moment of solidification is noted.

All the alloys of copper and tin are subject to liquation at the moment of solidification save those of which the composition corresponds to the formulæ $Sn\,Cu^3$ and $Sn\,Cu^4$. The liquation is slight for the alloy in which tin and copper are in the relation of 1 : 15, and considerable for the others, in such degree that it is impossible to determine the fusibility of any except the alloys $Sn\,Cu^3$ and $Sn\,Cu^4$.

Three series of experiments have been made. In the last two the wire wound around the bobbin of the galvanometer was much longer, and in one section ten times smaller than the wire which had been used in the former series.

This modification in the apparatus was made in order to increase the resistance of the thermo-electric circuit without reducing the sensitiveness of the instrument, and to lessen by this means the error which results from the variation in conductibility in the circuit, which is caused by variations of temperature.

Each day, at the beginning and at the close of the experiments, those results only were considered good which were obtained when the deviation was obviously the same in these two experiments.

M. Edmond Becquerel was very desirous of verifying my principal results with my pyrometer, and he found them proportional to the results obtained by him for the same bodies.

TABLE 1.

	Fixed points.	Deviations observed.			Relation of experiments II and III.
		I.	II.	III.	
Water boils	100° C.	23	19	10.5	1.81
Tin solidifies	228	57	46.5	24.2	1.92
Lead solidifies	228	89	59	32.0	1.84
Mercury boils	358	91	81	42.5	1.90
Sulphur boils	445	123	104	55.0	1.89
Antimony solidifies	*584	206	181	95.0	1.90
Alloy $Sn\,Cu^3$ solidifies	584	247	200	106.0	1.88
Alloy $Sn\,Cu^4$ solidifies	584	265	200	106.0	1.88
Cadmium boils	†720	335	200	115.0	1.88
Coin silver (899) solidifies	720	399	392	207.0	1.89
Cannon bronze solidifies	720	*406	392	207.0	1.89
Gold (899) solidifies	720	448	392	207.0	1.89
Copper solidifies	720	475	435	233.0	1.86

* M. Becquerel. † Approximate result.

I made a large number of experiments specially to determine the comparative fusibility of the alloys of tin and copper. They have always agreed with $Sn\,Cu^4$, and especially with $Sn\,Cu^3$, and have been very irregular with the others. These latter results are caused by the liquation of the alloys at the moment of solidification. In order to determine within what limits copper and tin separate from their alloys I first proposed to melt them in an iron ingot mold, as Levol did some large spherical masses, and analyze the different parts, but with one part the liquated alloy is not very hard, and with another part the proceeds of the mixture have not the sharpness of those resulting from the tests of the alloys of gold and silver, and I was obliged to give it up after a number of unsuccessful attempts.

Two series of experiments have been made:

1st. From 500 to 700 grammes of alloy were melted in cylindrical earthen tubes of three centimeters diameter and sixty centimeters in height.

The alloy was kept in the tube in a liquid state for ten hours, and left to cool very slowly in the middle of the hearth, covered with ashes.

To avoid oxidation the tubes were inclosed in a large earthen box where they were separated by coal-dust, and in each tube was placed coal, which floated over the metallic bath. When the ingot was cool the tubes were broken, and a portion taken from the top and the bottom of each alloy for trial.

2d. From 500 to 700 grammes of each alloy were melted in an earthern crucible and stirred constantly with an earthenware rod until solidification took place, so that the liquid portion did not remain viscous in the midst of the solidified mass. Then the portion subjected to analysis was poured off.

The following table shows that all the alloys of copper and of tin are subject to liquation, except those which correspond to the formulæ $Sn\ Cu^3$ and $Sn\ Cu^4$, which explains the impossibility of determining the point of fusion of any except these two. The liquation is greater in the alloys rich in tin than in those in which copper predominates; for it is only in the former that it has been possible to observe the different compositions at the top and bottom of the ingots obtained after long fusion followed by slow cooling.

TABLE 2.

Number of order.	Composition of alloy.	Quantity of tin; per cent. at the top and bottom of the bar.		Quantity of tin; per cent. found in the product last solidified.	Physical characteristics.
		Bottom.	*Top.*		
1	$Sn^5\ Cu$ { Cu .... 9.73 Sn^5 ... 90.27 }	87.87	92.90	98.50	Tin gray; soft, like that metal; non-crystalline.
2	$Sn^3\ Cu$ { Cu .... 15.21 Sn^3 ... 84.79 }	83.15	78.90	96.99	Tin gray; crystallizes when cooled slowly.
3	$Sn^2\ Cu$ { Cu ... 21.21 Sn^2 ... 78.79	81.81 74.97	84.56 77.40	94.40	Tin gray; crystallized; quite hard.
4	$Sn\ Cu$ { Cu .... 34.99 Sn 65.01	58.11 From 55 to 80	75.83	82.83	Whitish gray; crystallized; brittle.
5	$Sn\ Cu^2$ { Cu^2 ... 51.84 Sn .... 48.16 }	Assay lost		40.52	Bluish gray; like zinc; very crystalline; very brittle.
6	$Sn\ Cu^3$ { Cu^3 ... 61.79 Sn ... 38.21 }	37.29	37.66	*37.37 †37.30	Fine-grained; can be pounded in a mortar.
7	$Sn\ Cu^4$ { Cu^4 ... 68.28 Sn ... 31.72 }	30.44	30.83	30.91	White; foliated; fragile as glass.
8	$Sn\ Cu^5$ { Cu^5 ... 72.91 Sn ... 27.09 }	27.15	26.78	27.76	White, with yellowish reflections; crystalline; very hard.
9	$Sn\ Cu^6$ { Cu^6 ... 76.31 Sn .... 23.69 }	23.37	23.69	25.17	Yellowish; fine grained; very hard; malleable to dark red.
10	$Sn\ Cu^7$ { Cu^7 ... 79.02 Sn ... 20.98 }	21.00	21.32	24.85	Physical properties like the preceding.
11	$Sn\ Cu^8$ { Cu^8 ... 81.15 Sn ... 18.85 }	18.88	18.56	24.60	Physical properties like the preceding two.
12	$Sn\ Cu^{10}$ { Cu^{10} .. 84.33 Sn .... 15.67 }	15.18	15.18	20.06 24.50	Yellow; extremely tenacious.
13	$Sn\ Cu^{15}$ { Cu^{15} ... 89.00 Sn .... 11.00 }	15.18	15.18	13.10	Cannon bronze.

* Before fusion. † After 4 fusions in air.

§ II.—DENSITY OF THE ALLOYS OF COPPER AND TIN.

My first experiments were made on bars of different alloys, but it should be remarked that even supposing it were possible to avoid all blow-holes in the cooling, it is impossible to obtain comparable results because of variations in the texture of the bronzes. Some are not crystalline, others have a very fine grain, and some are in large, thin, tabular crystals. The bars on which I experimented in the former assays weighed between sixty and seventy grammes. They were melted in the same mold. In the second series of experiments, filings were taken from top and bottom of the ingots which had been used in the preceding trials, in order to make two comparable assays for every alloy. These filings were made with a new file, and were afterwards submitted to the action of a magnet in order to separate the particles of iron that might have been detached from the file. The density was estimated in this latter case by a hydrometer. In one case the filings being placed in this vessel, the water was raised to the boiling point, and then it was kept several hours in vacuum.

The following table recapitulates these determinations:

TABLE 3.

Formula of the alloy.	Centesimal composition.	Density of the bars.	Density of the filings.		Calculated density.	Difference.
$Sn^5 Cu$	Sn....90.27 Cu.... 9.73	7.52	7.23 7.32	7.28	7.43	−0.15
$Sn^4 Cu$	Sn....88.16 Cu .. 11.81	7.50	7.04 7.58	7.31	7.46	−0.15
$Sn^3 Cu$	Sn....84.79 Cu....15.21	7.53	7.43 7.44	7.44	7.50	−0.06
$Sn^2 Cu$	Sn....78.79 Cu....21.21	7.74	7.35 7.84	7.59	7.58	+0.01
$Sn Cu$	Sn....65.01 Cu....34.99	8.12	7.93 7.87	7.90	7.79	+6.11
$Sn^2 Cu^3$	Sn....55.33 Cu....44.67	8.30	8.00 8.11	8.06	7.98	+0.13
$Sn Cu^2$	Sn....48.16 Cu....51.84	8.57	8.07 8.23	8.15	8.04	+0.11
$Sn Cu^3$	Sn....38.21 Cu....61.79	8.96	8.86–8.84–8.99 8.93–8.92–8.90	8.91	8.21	+0.70
$Sn Cu^4$	Sn... 31.72 Cu....68.28	8.80	8.61–8.85 8.80	8.75	8.32	+0.43
$Sn Cu^5$	Sn... 27.09 Cu....72.91	8.87	8.73–8.59 8.51–8.65	8.62	8.40	+0.22
$Sn Cu^6$	Sn .. 23.60 Cu....76.31	8.91	8.77–8.85 8.54	8.72	8.46	+0.26
$Sn Cu^7$	Sn ... 20.98 Cu....79.02	8.90	8.67 8.77	8.72	8.50	+0.22
$Sn Cu^8$	Sn....18.85 Cu....81.15	8.86	9.06–8.62 8 83	8.84	8.54	+0.30
$Sn Cu^{10}$	Sn....15.67 Cu....84.33	8.83	8.72–9.04 8.98–8.73	8.87	8.60	+0.27
$Sn Cu^{15}$	Sn... 11.00 Cu... 89.00	8.80	8.97–8.74 8.81	8.84	8.69	+0.15

It was my intention to bring these densities back again to zero, but the uncertainty which prevails as to the value of the coefficients of dilatation of the metals, and the differences that they present according to the condition in which the metal is found, either free or combined, have led me to give the numbers which have been deduced by experiment.

These results verify the known fact that copper and tin contract in uniting. Still, when the proportion of tin is very great, the reverse seems to take place, but the difference is very slight. It is an undoubted fact that the contraction is very slight and regular up to the alloy Sn Cu^2; that from this point it increases suddenly till it reaches a maximum, when the copper and tin are in the relation of 3 to 1. The existence of this maximum of contraction had been previously announced by Calvert and Johnson,* contrary to the opinion of other experimenters who had maintained that the contraction increases with the proportion of tin.†

The errors on this point, and the differences which exist between certain numbers of Calvert and Johnson, are explained by §§ IV and V, and by the fact that former experimenters, and the able English chemists themselves, worked upon ingots and not upon filings.

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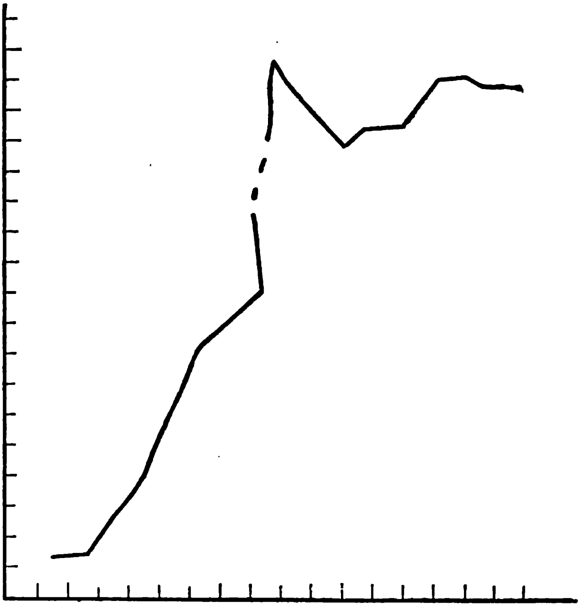
* Calvert and Johnson, *Moniteur Scientifique*, t. iv, p. 225, 1862.

† Briche, *Traité de Chimie appliquée aux Arts*, Dumas, t. iii, p. 517.

To begin with the alloy $SnCu^3$, the density first diminishes and then increases quite regularly; but the density of the alloys richer in copper, as cannon bronze, is inferior to that of the alloy $SnCu^3$, which, however, contains only 61.79 per cent. of copper. The curve shown in the following table gives an idea of these variations in density:

TABLE 4.



Curve representing the comparative densities of the alloys of copper and tin.

It will be noticed that a great number of assays have been made for the alloy $SnCu^3$ and that all are concordant; that the density of the bar verifies the results obtained with matter in grain and in powder. The other properties of this alloy are equally exceptional. While all the preceding have the gray hue of tin, and while those that follow are white or yellow, this alone is distinguished by a bluish color. It exhibits no liquation, for after four successive fusions the last solidified product possessed the composition that it had immediately after the first casting.

Consequently the alloy $SnCu^3$ is, in the series of alloys of copper and tin, what the alloy Ag^3Cu^4 is in the series of alloys of copper and silver as shown by Levol.*

§ III.—HARDNESS.

I have tried various methods for comparing the alloys of copper and tin in respect to their hardness. None have given sufficiently satisfactory results to enable me to express their relative hardness by numbers. I finally made use of an apparatus invented by an ingenious engineer of

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* *Annales de Chim. et de Phys.*, 3d *série*, t. xxxvi, p. 193.

Paris, M. Magna, an apparatus which, since my experiments, has been used to test rails on an Eastern railroad.

It consists of a weight, which slides without sensible friction in an iron tube, where it can be made to fall from a variable and determined height. This weight strikes a punch of tempered steel, which rests upon the specimen to be tested. This specimen is firmly fastened upon a block of steel attached to the tube and resting upon a block of wood.

But very imperfect comparisons are obtained, because the same shock produces a considerable impression on a soft alloy, and a scarcely observable dint, which is very difficult to measure, on a hard alloy. If, to avoid this difficulty, we strike a large number of blows, the metal hardens, and from thirty to sixty blows produce only insignificant results.

We cannot expect to destroy the effect of the compression by annealing, because the depths of the impression produced are variable and the surface distorted, when they should be plane and parallel. We can, at most, compare by this means, as we shall see further on, only metals differing but little in hardness. I can only say that the hardness determined by this means increases from tin to the alloy containing copper and tin in the relation of equivalents.

From this alloy up to that which corresponds to the formula $Sn\ Cu^5$ the metal is too brittle to be assayed. The hardness of the bronze of sonorous instruments is such, that the punch is not sensibly injured by 100 successive shocks, or else it is shattered.

Hardness diminishes from this alloy to copper.

We will now examine particularly the cannon bronzes.

§IV.—BRONZE USED IN MAKING SONOROUS INSTRUMENTS.

$$\begin{array}{r}
Cu = 78 \text{ to } 82 \\
Sn = 22 \text{ to } 18 \\
\hline
100
\end{array}$$

D'Arcet having proved that this bronze, unlike steel, is softened by tempering and hardened by annealing, it was proposed to determine the modification which its volume undergoes in tempering, annealing, and mechanical action.

1. *Alternate tempering and annealing.*

Ingots of this bronze were melted at a sufficiently high temperature in a cylindrical iron ingot-mold. Solidification took place in a few seconds. For the fusion, the copper was first heated alone in an earthen crucible; two or three pieces of coal were put into this vessel to avoid oxydization. When the copper was melted the tin was put in, and being stirred a little, it melted almost immediately. The ingots were cut and then carefully filed. As in all the following experiments the work was performed in the same way, we will describe it once for all.

The density was determined in all the experiments with two exact balances. That used for weighing in water had been made especially for that use at the laboratory of the mint. Boiling water was used, and the ingots were suspended by a horse hair, the trifling weight of which (0^{gr} 0.17 to 0^{gr} 0.20) was deducted.

The temperature at which most of the following determinations were made necessarily varied, but for each series of experiments the temperature did not vary more than three degrees, the balances being placed in an isolated and very cool position. The weight of the specimens was comparatively large, and varied frequently within the somewhat extended limits. In the first series of experiments each ingot weighed from 85 to 90 grammes. The specimens to be tempered and annealed were placed side by side in a sheet-iron box placed in another of cast-iron filled with coal dross, and covered with a cast-iron plate. When the metals were observably red, those which were to be tempered were plunged into cool water, and the interior case again closed, recovered with coal dross, and the whole left to cool slowly, the fire being covered with ashes.

This was done in the evening, and the specimens were not taken out again till the next day, and then they were so warm that they could hardly be held in the hand.

TABLE 5.

Bronze at 20.80 per cent. of tin.

	Density.									
	I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.	X.
After casting	8.787	8.858	8.825	8.862	8.863	8.780	8.715	8.822	8.842	8.747
After tempering	8.823	8.915	8.863	8.896	8.906	....	....	....	....	....
After annealing	8.817	8.907	8.847	8.886	8.894	8.808	8.739	8.844	8.863	8.871
After tempering	8.849	8.927	8.874	8.907	8.922	....	....	....	....	....

TABLE 6.

Bronze at 18 per cent. of tin.

	Density.	
	I. $P=71^{gr}.490$.	II. $P=86^{gr}.775$.
After casting	8.737	8.873
After annealing	8.733	8.863
After tempering	8.763	8.911
After annealing	8.753	8.889
After tempering	8.775	8.926
After tempering	8.786	8.927

A bar of two kilogrammes was melted in order to obtain some very homogeneous matter, because in the preceding experiment, where the operations had been carried on with only a little metal, the cooling had been made too rapid by the addition of tin, and it was made very hot before the tin was put in. The bar was cut into strips, and we experimented upon four of them.

TABLE 7.

Bronze at 20 per cent. of tin.

	Density.	
	I. $P=132^{gr}.735$.	II. $P=128^{gr}.885$.
After tempering	8.704	8.719
After annealing	8.712	8.728
After tempering	8 730	8.747
After annealing	8.724	8.744
After tempering	8.756	8.763
After annealing	8.741	8.759
After a second annealing	8.751	8.769
After tempering	8.775	8.793

TABLE 7—Continued.

	III. $P=136^{gr}.572$.	IV. $P=136^{gr}.494$.
After annealing	8. 752	8. 686
After tempering	8. 780	8. 713
After annealing	8. 777	8. 714
After tempering	8. 804	8. 736
After annealing	8. 815	8. 750
After tempering	8. 841	8. 774
After a second tempering	8. 850	8. 787
After annealing	8. 807	8. 760

It is evident from these three series of experiments that tempering arguments considerably the density of bronze rich in tin, and that annealing evidently diminishes the density of tempered bronze. Still the effect of slow cooling by no means destroys the effect of tempering, for the density continues to increase till it becomes remarkable.

2. *Alternate action of heat of shock and of compression.*

The four preceding specimens were submitted to the action of the screw-press, but as this bronze is brittle, it was merely compressed strongly by the exertions of six men, instead of giving it a sudden blow. The two tempered pieces resisted. The two annealed pieces were broken, giving, the one a fragment weighing $80^{gr}.335$, and the other a fragment weighing $64^{gr}.644$, with which we worked. Two samples were successively annealed; two others successively tempered. The results are given in the following table:

TABLE 8.

	Density.			Density.	
	I. $P=128^{gr}.238$.	II. $P=64^{gr}.644$.		III. $P=121^{gr}.537$.	IV. $P=80^{gr}.335$.
After compression	8. 796	8. 775	After compression	8. 782	8. 792
After tempering	8. 804	8. 804	After annealing	8. 767	8. 803
After compression	8. 805	8. 789	After compression	*8. 760	†8. 796
After tempering	8. 809	8. 826	After annealing	8. 763	8. 814
After compression	8. 818	8. 840	After compression	‡8. 766	8. 812
After tempering	8. 819	8. 845	After annealing	8. 772	8. 824
After compression	8. 827	8. 865	After compression	8. 776	8. 817
After tempering	8. 828	8. 866	After annealing	8. 788	8. 844
After compression	8. 837	8. 889	After compression	8. 795	8. 835
After tempering	8. 841	8. 897	After annealing	8. 799	8. 849
After shock	8. 850	8. 922	After shock	8. 805	8. 842
After tempering	8. 857	8. 925	After annealing	8. 823	8. 866
After shock	8. 870	8. 939	After shock	8. 832	*8. 851
After tempering	8. 871	8. 937	After annealing	8. 846	8. 856
After shock	8. 877	8. 948	After shock	8. 836	8. 841
After tempering	8. 880	8. 944	After annealing	8. 850	8. 829
After shock	8. 888	8. 955	After shock	*8. 840	*8. 824
After tempering	8. 887	8. 951	After annealing	8. 882	8. 845
After shock	8. 898	8. 952	After shock	§8. 854	8. 836
After tempering	8. 906	8. 952	Gain in density	0. 072	0. 044
The density increased from	0. 102	0. 177			

* Cracks. † Cracks. The fins are filed off. ‡ Crack on the edge. § Breaks.

The prominent fact which is shown by these numbers is that the density is increased by mechanical action, tempering, and annealing, in a remarkable degree.

The increase is greatest in the tempered specimens.

It should be remembered that but limited confidence can be placed in the figures obtained for the annealed metal, because it cracks and splits on the edges, while it does not alter at all when it has been tempered.

As it is stated in books that tempering has the effect of diminishing the density of this bronze,* I examined this point very carefully, and made many other experiments, varying the composition (from 18 to 22 per cent. of tin), the form, and the weight of the specimens. All are concordant, as is shown by the following table:

TABLE 9.

	Density.			
	I.	II.	III.	IV.
Bronze melted	8.872	8.682	8.822	8.527
Bronze tempered	8.907	8.723	8.836	8.543
Bronze hammered	8.915	8.843	8.895	8.771
Bronze tempered	8.928	8.842	8.904	8.777
Bronze hammered	8.938	8.909	8.923	8.871
Bronze tempered	8.947	8.910	8.930	8.877
Bronze hammered		8.932		8.918
Bronze tempered				8.927
Bronze hammered				8.937
Bronze tempered				8.945
Bronze hammered				8.944
Increase of density	0.075	0.250	0.108	0.417

The thickness was reduced in these experiments from seventeen to seven millimeters.

When this bronze is cooled slowly the experiments are less convincing, because the metal breaks, or at least cracks easily, under shock. However, as my first object in undertaking this work was to clear up these obscure phenomena of tempering, and as I count for thus clearing them up upon the variations of density, I made numerous experiments, in some compressing the material slightly, and in others preserving it from sudden shock by an intervening body.

I give here some of the results:

TABLE 10.

	Density.	
	I.	II.
After casting	8.660	8.695
After slow cooling	8.653	8.683
After compression	8.738	8.750
After slow cooling	8.790	8.793
After compression	8.833	8.831

Thus there is always an increase in density whether the bronzes rich in tin be tempered or slowly cooled after compression.

These experiments confirm most clearly the fact affirmed by D'Arcet, that tempering softens the bronzes rich in tin, for we can flatten in the press the tempered bronzes, while it is only exceptionally, or by taking

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* Dussaussoy, *Annales de Chimie et de Physique*, t. v. p. 228, we read:

Alloy of copper 80 and of tin 20.

	Non-tempered.	Tempered.	Tempered and softened.	Heated and cooled slowly.
Density	8.670	8.520	8.611	8.660

Annales de Chimie et de Physique, t. xxx (Novembre, 1873), 24.

special precautions, that we are able to subject them to the same mechanical action without breaking them when they have been heated and cooled slowly.

This fact, being the inverse of that which is observed with steel, led me to examine the nature of the variations which the density of steel undergoes when placed under the conditions described.

3. *Action of tempering and annealing on steel.*

Reaumur and Rimmann admitted that the volume of tempered steel is greater by $\frac{1}{48}$ than that of steel which has not been tempered. Karsten, without absolutely contesting this opinion, does not consider it clearly demonstrated that steel diminishes in density by tempering. Colonel Caron, in his celebrated works on steel, has shown that tempering increases the volume of steel. Thus, after thirty successive temperings, the density which was 7.817 became 7.743,* and he concluded from his researches that the effect of tempering might be likened to the effect produced by the blow of a hammer on red-hot metal.

The steel experimented upon was of a very good quality used at the mint in Paris. The samples weighed from 130 to 150 grammes.

TABLE 11.

	Density.		
	I.	II.	III.
Bars forged	7.839	7.846	7.839
Bars forged, after tempering	7.735	7.749	7.738
Bars forged, after annealing	7.831	7.833	7.828
	IV.	V.	VI.
Bars forged	7.841	7.839	7.841
Bars forged, after annealing	7.843	7.845	7.843
Bars forged, after tempering	7.758	7.763	7.755

Thus tempering produces on steel forged or annealed an inverse effect to that which it produces on bronzes rich in tin; it diminishes its density instead of increasing it, from which it may be seen that tempering diminishes the density of annealed steel and makes it hard, while tempering increases the density of annealed bronze and makes it soft.

4. *Action of the press or of the roll, and of annealing, on steel.*

Two steel plates which had been used in the preceding experiments were employed.

TABLE 12.

	Density.	
	P=85^{gr}.830.	P=83^{gr}.465.
Forged steel	7.845	7.847
Forged steel, after one annealing	7.849	7.849
Forged steel, after one action of press	7.839	7.843
Forged steel, after second annealing	7.844	7.848
Forged steel, two impacts	7.838	7.839
Forged steel, three annealings	7.844	7.845
Forged steel, three impacts	7.837	7.841
Forged steel, four annealings	7.849	7.854
Forged steel, four impacts	7.849	7.849
Forged steel, five annealings	7.844	7.845

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* *Comptes Rendus des Séances de l'Académie des Sciences*, January 5, 1873.

As the variations in density recapitulated in the preceding table are very slight, I tried to render them greater by passing small bars of well-annealed steel under a steel roll. The following table shows that if the results are in the same direction they are no more pronounced, and the experiment is very soon terminated by the breaking of the metal.

TABLE 13.

	Density.	
	P=77^{gr}.242.	P=76^{gr}.595.
Steel annealed	7.832	7.833
Steel rolled	7.827	7.824
Steel annealed	7.829	7.830
Steel rolled	7.822	7.820
Steel annealed	7.826	7.827
Steel rolled	7.816	7.822

The differences that bronze and steel present when alternately annealed and tempered are again encountered here, but in a less degree. While the mechanical action increases the density of the annealed bronze, it very slightly but still sensibly diminishes the density of annealed steel, and, on the whole, tempering and shock increase the density of annealed bronze, while they diminish the density of annealed steel.

But the variations are very decided for bronze and very slight for steel.

5. *Bronzes rich in tin.*

Examining Table 12 we see that the density is by annealing brought back to what it was before the action of the press; after five annealings and four powerful blows of the press, there was no sensible variation, and consequently we see how a block of annealed steel submitted to compression in making coin, sustains twenty, thirty, and even many more annealings and shocks, without any apparent difference in its work. Annealing restores the metal to the condition in which it was before the mechanical treatment.

Immediately following the researches published by D'Arcet in 1814* on the softening of the bronzes by tempering, experiments were made in different places, and particularly at *l'École des Arts et Metiers* at Châlons, on the tamtams and cymbals, instruments that we did not then manufacture and do not now in European countries, but which we obtain from China or from Turkey in Asia, and M. Maillard, head of the foundry of the "École" at Châlons, succeeded in making some of a tempered alloy containing—

$$\left.\begin{array}{ll}\text{Copper} \ldots\ldots\ldots\ldots & 80.5 \\ \text{Tin} \ldots\ldots\ldots\ldots\ldots & 19.5\end{array}\right\} 100.$$

It was thought that this process was the same as that employed by the Orientals, and this opinion is to-day generally accepted among chemists.

Afterwards, St. Julien advanced the opinion that the Chinese worked the bronze red hot,† but D'Arcet held that St. Julien had been led into error,‡ because bronze greatly increases in density when heated, while the density of the Chinese instruments is very much less than that of heated bronze, and further, this bronze can be pulverized at red heat.

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* D'Arcet, *Bulletin de la Société d'Encouragement*, p. 289, 1814.

† St. Julien, *Annales de Chim. et de Phys.*, t. liv, p. 329, 1833.

‡ D'Arcet, *Annales de Chim. et de Phys.*, t. liv, p. 331, 1833.

In view of this contradictory testimony, I consulted the best instrument-makers of Paris, MM. Gautrot and Lecomte, who assured me that working this bronze cold is impracticable industrially, even after tempering, and I knew, on the other hand, that M. Maillard had encountered great difficulties in making these instruments, as great numbers of them were broken in the course of the work, and they are all thicker than the Chinese instruments.

I analyzed at that time fragments of the real Chinese instruments, and I found

Tin in 100 parts.
22.80
21.20
20.80
19.67

I ascertained the density of two good-sized specimens. It was—

For one	8.909
For the other	8.948

I submitted to cherry-red heat some bronze containing 20 per cent. of tin, and I found, as D'Arcet had shown, that this metal is reduced to powder by blows. I then sought to ascertain if this metal would not, like zinc, be malleable at the intermediate temperatures. About 100 to 200 degrees it is brittle as when cold or at a cherry-red heat, but at dark-red, and a little under that temperature, it can be forged as easily as iron or aluminium bronze. At these temperatures it flattens without breaking under the heaviest blows of the hammer; it is so easily flattened that it can, in some cases, be reduced from a thickness of 14 millimeters to that of 1 to 2 millimeters, and if the temperature be raised a little it becomes so soft that it can be wound upon itself by subjecting it repeatedly to slight shocks. In a word, the work is thus done with greater accuracy and rapidity, and becomes, industrially speaking, practicable.

It remains to be considered whether the density approaches to that which is obtained by cold hammering and to that of the Chinese metal.

With this object the two tempered specimens which formed the subject of Table 8 were heated red-hot, and the following results obtained:

TABLE 14.

	Density.	
	I.	II.
Metal tempered	8.906	8.932
Metal hammered at red heat, diminishing its weight one quarter	8.953	8.942
Metal tempered anew	8.958	8.924
Metal hammered again more gently on account of its brittleness	8.939	8.924
Metal tempered again	8.933	8.934
Metal hammered gently	8.920	8.924

The metal having been cold-beaten for a long time, I repeated these operations at a higher temperature with new metal.

TABLE 15.

	Density.
Cast metal	8.764
Cast metal after first hammering at dark-red heat	8.893
Cast metal after second hammering at dark-red heat	8.941
Metal after third hammering at dark-red heat	8.948
Metal after fourth hammering at dark-red heat	8.943
Metal after fifth hammering at dark-red heat	8.927

The thickness was reduced from six millimeters to one.

The same experiments at high temperature were repeated on the metals containing from 18.5 to 21.5 of tin, when they had been cast at a very high temperature.

TABLE 16.

	Density.
Bronze at 18.5 per cent. tin, after casting at a high temperature	8.882
The same after prolonged hammering at dark-red heat	8.938
Bronze at 20 per cent. tin, after casting at a high temperature	8.912
The same after prolonged hammering at dark-red heat	8.920
Bronze at 21.5 per cent. tin, after casting at a very high temperature	8.938
The same after prolonged hammering at dark-red heat	8.929
Bronze at 20 per cent. tin, rolled at red heat	8.819 8.837 8.865 8.873

The thickness was reduced from 6 millimeters to 1.

Two facts follow from these experiments:

1st. Working hot does not increase the density more than working at low temperature.

2d. The metal attains this density very rapidly by the working hot, and without danger of rupture; while cold the action is extremely slight and very difficult.

If I add that the Chinese tamtams bear traces of numerous hammerings, which indicate that the metal was worked when it was softened by heat, it will, I think, be admitted, as I stated when I published these results,* that the working cold is not carried on in China as D'Arcet supposed, and that the method of fabrication attempted at *l'École des Arts et Metiers* at Châlons is not the method practised in the East, but that the metal is worked there *hot*, as St. Julien declared.

Had there remained any uncertainty it would have been removed when, some days after the publication of these researches, MM. St. Julien and Champion published on their side a work in which M. Champion stated that he had seen this work in China, and that the metal was heated.†

M. Champion and myself unite to introduce this desideratum into the industrial arts of European countries, and we have succeeded in making, at the works of MM. Cailar and Guin, two tamtams, which have the external characteristics and the sonorousness of the Chinese instruments. But we utilized the facility with which I had observed this bronze to flatten to shorten the operation and to diminish hand labor, by first subjecting the cast alloy, very thick and red hot, to the action of the rolling-mill, which machinery, according to M. Champion, is unknown to the Chinese, and which, in every case, he ascertained by observation was not employed by them in reducing bronze for the manufacture of sonorous instruments.

§ V. BRONZES LESS RICH IN TIN APPROACHING CANNON-BRONZE IN THEIR COMPOSITION.

$$\begin{array}{rl} Cu = & 94 \text{ to } 88. \\ Sn = & 6 \text{ to } 12. \\ \hline & 100 \end{array}$$

The bronzes were submitted to the same operations as the preceding.

1. *Tempered and annealed alternately.*

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* *Comptes Rendus des Séances de l'Académie des Sciences*, t. lxix, p. 343.

† *Industries anciennes et modernes de l'Empire Chinois*, Lacroix, 1869.

TABLE 17.

Alloy of $\left.\begin{matrix}88\ \text{Cu}\\10\ \text{Sn}\end{matrix}\right\}100$

	Density, P = 47^{gr}.806.
After tempering	8.625
After annealing	8.632
After tempering	8.624
After annealing	8.635
After tempering	8.632

TABLE 18.

Gun-bronze, at $\left.\begin{matrix}90\ \text{Cu}\\10\ \text{Sn}\end{matrix}\right\}100$

	Density.			
	I. P=69^{gr}.686.	II. P=70^{gr}.902.	III. P=112^{gr}.468.	IV. P=104^{gr}.783.
After casting	8.564	8.677	8.684	8.491
After tempering	8.516	8.635	8.657	8.428
After annealing	8.528	8.643	8.670	8.431
After tempering	8.532	8.645	8.671	8.437
After annealing	8.536	8.648	8.674	8.434
After tempering	8.529	8.648	8.673	8.436
After annealing	8.526	8.643	8.676	8.436
After tempering	8.526	8.626	8.664	8.436

	Density.	
	P=69^{gr}.198.	P=112^{gr}.520.
After casting	8.541	8.705
After annealing	8.491	8.689
After tempering	8.495	8.684
After annealing	8.504	8.692
After tempering	8.505	8.693
After annealing	8.479	8.651
After tempering	....	8.661

TABLE 19.

Bronze at $\left.\begin{matrix}94\ \text{Cu}\\6\ \text{Sn}\end{matrix}\right\}100$

	Density, P = 141^{gr}.830.
After casting	8.537
After tempering	8.491
After annealing	8.501
After tempering	8.502
After annealing	8.507
After tempering	8.505

	Density.	
	II. P–152^{gr}.516.	III. P=76^{gr}.599.
After casting	8.519	....
After annealing	8.492	8.807
After tempering	8.491	8.806
After annealing	8.496	8.802
After tempering	8.495	8.804
After annealing	8.496	8.809

These numbers show that the bronzes containing but little tin, susceptible of being cold-hammered, or even flattened like gun-bronze, do not increase in density when tempered or annealed like the preceding.

2. *Annealed or tempered and rolled alternately.*

TABLE 20.

Bronze $\left.\begin{matrix}94\ Cu\\ 6\ Sn\end{matrix}\right\}100$

	Density.	
	I. $P-122^{gr}.130$.	II. $P-65^{gr}.590$.
After casting	8. 541	....
After rolling	8. 672	8. 758
After tempering	8. 643	8. 761
After rolling	8. 722	8. 838
After tempering	8. 694	8. 833
After rolling	8. 772	8. 871
After tempering	8. 770	8. 872
After rolling	8. 827	8. 921
After tempering	8. 824	8. 926
After rolling	8. 897	8. 929
After tempering	8. 907	8. 936
After rolling	8. 918	8. 939
After tempering	8. 919	8. 739
After rolling	8. 933	....
The density increases from	0. 392	0. 181

	Density.	
	III. $P-127^{gr}.920$.	IV. $P=81^{gr}.109$.
After casting	8. 541	....
After rolling	8. 669	8. 773
After annealing	8. 627	8. 772
After rolling	8. 722	8. 836
After annealing	8. 729	8. 839
After rolling	8. 801	8. 874
After annealing	8. 801	8. 875
After rolling	8. 851	8. 913
After annealing	8. 852	8. 923
After rolling	8. 904	8. 928
After annealing	8. 919	8. 929
After rolling	8. 922	8. 931
After annealing	8. 931	8. 934
After rolling	8. 935	....
The density increases from	0. 394	8. 161

The metal was reduced from a thickness of ten millimeters to that of one.

Comparing these results with those given by the bronzes rich in tin, we find that tempering and annealing give about the same increase in density, while the increase was much greater for the tempered metal in the alloys rich in tin.

These alloys seemed to be as easily worked after annealing as after tempering.

An attempt was made to verify this last point by operating under practical conditions; that is to say, by reheating the metal in the air, working on bronze of 10 and bronze of 6 per cent. tin, which was in the form of strips four millimeters wide. The mechanical action and heat were the same; the only difference was in the cooling; while one specimen was tempered when red hot, the other was left out in the air. The results are given in the following table:

TABLE 21.

1. *Bronze at* 10 *per cent. tin.*

	Density. I. $P=66^{gr}.928$.
After 6 impacts of the press	8.887
After annealing	8.833
After 9 impacts of the press	8.905
After annealing	8.902
After 96 impacts (and 32 annealings)	8.930
After annealing	8.935

	Density. II. $P=66^{gr}.958$.
After 6 impacts of the press	8.898
After tempering	8.894
After 9 impacts of the press	8.904
After tempering	8.897
After 96 impacts (32 temperings)	8.904
After tempering	8.905

2. *Bronze of* 6 *per cent. tin.*

	Density. III. $P=66^{gr}.002$.
After 6 impacts of the press	8.924
After annealing	8.923
After 9 impacts of press	8.936
After annealing	8.928
After 57 impacts (19 annealings)	8.931
After annealing	8.932

	Density. IV. $P=65^{gr}.242$.
After 6 impacts of press	8.928
After tempering	8.924
After 9 impacts of press	8.929
After tempering	8.923
After 57 impacts (19 temperings)	8.934
After tempering	8.935

The tempering and the annealing take place in a similar manner, almost identically the same for bronze at 6 per cent. tin. Thus the density after 72 blows of the press, alternated with 24 annealings, increases from 8.924 to 8.932, and by tempering, from 8.928 to 8.935.

The workman observed no differences in the hardness of the metal annealed or tempered, and the ease of working secured was the same.

Two sheets of these bronzes were prepared, of a thickness of 15 millimeters, and these were subjected to the ordinary operations of coining after they had been cut in two, care being taken to have one of these parts annealed and the other tempered. When they had been reduced to strips 5 centimes in width, that is to say, 1 millimeter, the strips were cut and weighed.

TABLE 22.

1. *Bronze at* 10 *per cent. tin.*

	gr.
Weight of 15 strips after 3 temperings	76.90
Weight of 6 strips after 3 temperings	32.36
Weight of 10 strips after 3 temperings	53.50
Weight of 15 strips after 3 annealings	77.27
Weight of 6 strips after 3 annealings	32.07
Weight of 10 strips after 3 annealings	54.70

2. *Bronze at 6 per cent. tin.*

	gr.
Weight of 15 strips after 3 temperings	73.82
Weight of 6 strips after 3 temperings	32.14
Weight of 10 strips after 3 temperings	48.95
Weight of 15 strips after 3 annealings	73.98
Weight of 6 strips after 3 annealings	31.49
Weight of 10 strips after 3 annealings	51.00

No difference was observed in working the alloys whether annealed or tempered, and the weight of the annealed strips did not differ materially from that of the tempered ones.

The director of the mint at Paris, M. Bijon, to whom I also owe many thanks for all the facilities he procured for me in the prosecution of these researches, assured me that no differences had been observed in the working until at one time, work not being very urgent, the plates were left to cool in the air instead of being tempered in water. It is preferable to cool the bronze rapidly in order to diminish its oxidization, and especially to detach the scales of oxide which form during the reheating, and which have the double inconvenience of soiling the rolls and of injuring the plates.

3. *Liquation in gun-bronzes.*

Liquation is not so considerable as is generally supposed. The following table recapitulates some of the numerous analyses which were made of cannon during the siege of Paris, with my colleague, M. Desmarais, at M. Thiébault's, and at Cailar & Guin's:

In table 24 will be found the analysis made by M. Drouin and myself on the different parts of the cannon cast at the *École des Arts et Metiers* of Angers, for which I am indebted to the courtesy of M. Soux, chief of the millwright shop of this establishment.

TABLE 23.

INTERIOR.

Samples taken.	Sn.	Zn.	Pb.	Cu.*
No. 1.				
At the breech	8.72	1.80	0.92	88.56
At top of trunnion	7.18	2.00	0.74	90.08
Toward the muzzle	7.08	1.60	0.83	90.49
No. 2.				
At the breech	9.85	2.40	1.86	85.89
At the trunnion	9.44	2.20	1.86	86.50
Toward the muzzle	8.84	2.40	1.86	86.90
No. 3.				
At the breech	9.44	0.93	0.90	88.43
At the trunnion	9.74	1.11	0.60	88.55
Toward the muzzle	8.98	0.93	0.85	89.24

EXTERIOR.

Samples taken.	Sn.	Zn.	Pb.	Cu.*
No. 1.				
At the breech	8.74	2.00	0.83	88.43
At top of trunnion	8.72	2.00	0.93	88.35
Toward the muzzle	7.70	1.60	0.83	89.87
No. 2.				
At the breech	9.96	1.80	1.86	86.38
At the trunnion	9.85	2.40	1.86	85.89
Toward the muzzle	9.66	2.40	1.86	86.08
No. 3.				
At the breech	9.93	1.21	0.80	88.06
At the trunnion	8.72	1.11	1.00	89.17
Toward the muzzle	8.92	1.21	0.80	80.07

* Determined by difference.—*Ann. de Chim. et de Phys.*, 4 série, t. xxx, 1873, 25.

TABLE 24.

	m.
Length of the cannon with its sinking head	2,512
Length of the sinking head	1,500

The inner shavings were taken from a cylinder of 65 millimeters diameter having the same axis as the cannon. They were thoroughly washed in ether.

INTERIOR.

Distance from the breech.	Sn.	Pb.*	Zn.	Cu.†
M.				
0.40	8.965	0.165	1.600	89.270
0.60	9.014	0.165	2.000	88.821
0.80	9.014	0.165	2.200	88.621
1.00	8.726	0.165	1.200	89.909
1.20	9.046	0.165	0.800	89.989
1.40	8.732	0.165	1.200	89.903
1.60	8.762	0.165	0.600	90.473
1.80	8.999	0.165	0.800	90.036
Mouth.	8.762	0.165	2.100	88.973
Average of tin in the interior, 8.907.				
EXTERIOR.				
0.40	9.662	0.165	1.600	88.573
0.60	9.282	0.165	1.600	88.953
0.80	9.454	0.165	2.000	88.381
1.00	9.676	0.165	1.200	88.959
1.20	9.581	0.165	0.800	89.454
1.40	9.550	0.165	1.400	88.885
1.60	9.314	0.165	2.000	88.521
1.80	9.534	0.165	1.000	89.301
Sinking head at $0^{m}.65$ from the muzzle,	9.344	0.165	0.100	90.391
Average of tin at the exterior, 9.507.				

* Average of total lead found in the different parts.

† Determined by difference.

The part of the cannon which is in the axis of the piece, and which is cut away by the drill, is not homogeneous, especially toward the breech. Crystalline particles of gray tint were found there, which being separated as carefully as possible gave upon analysis:

Tin	12.30	11.21	13.89	14.49
Zinc	3.20	5.40	6.40	14.49

It does not follow that the central parts are richer in tin. On the contrary it has been shown by experiment that the exterior is richer in tin than the interior. This last fact, which clearly follows from the preceding tables, had been previously stated by Colonel Dussanssoy, contrary to the opinion previously held at cannon founderies.

The following table does not indicate that the sinking head may have the effect of increasing the density of the piece as has also been supposed.

TABLE 25.

Distance from the breech.	Quantity of tin, per cent.	Density.	Distance from the breech.	Quantity of tin, per cent.	Density.
0.20	10.498	8.472	1.20	9.291	8.618
0.40	9.065	8.539	1.40	9.048	8.549
0.60	9.140	8.539	1.60	8.969	8.500
0.80	8.752	8.549	1.80	8.526	8.458
1.00	9.039	8.460	2.00	8.530	8.374

4. *Manufacture of medals.*

Analysis of antique medals shows that though the ancients sometimes used copper for this purpose, they ordinarily employed bronze in which the proportion of tin varied between large limits (from 1 to 25 per cent.). The manufacture of medals with a bronze rich in tin is not possible at the present day on account of its hardness, and because considerable relief is necessary, while it was very slight in the medals of antiquity. Bronze has been wholly given up in our own country and copper substituted for it, but copper also presents some serious inconveniences. It rusts badly, has no ring, its red tint is not artistic, and this is concealed by an artificial bronzing which adheres poorly, and which causes different medals to vary in tone.

In 1828 M. de Puymaurin made a large number of experiments and continued them until 1832, after which an alloy of 94 copper, 4 tin, and 2 zinc was adopted, of which from time to time medals were manufactured until 1847, at which time it was entirely given up on account of the hardness of the metal leading to a deterioration of the coin. The hardness of bronze increases in fact very rapidly with the proportion of tin, and the following is the average of many experiments with the apparatus described above:

	Impacts necessary in order to obtain a depression of—	
	4^{mm}.	1^{mm}.
Copper	19	7
Bronze, with 97 parts copper	23	8 to 9
Bronze, with 96 parts copper	27	10
Bronze, with 95 parts copper	38	14
Bronze, with 94 parts copper	40	15
Bronze, with 90 parts copper	Did not succeed with 70 blows.	

After these experiments various medals were struck at the mint in Paris, with different alloys in the ordinary working conditions. The differences, which are unimportant for medals less than 35 millimeters, become more noticeable when the dimensions attain to 50 millimeters. There were necessary in this latter case—

With pure copper	7 compressions.
With bronze with 97 parts copper	10 compressions.
With bronze with 96.5 parts copper	12 compressions.
With bronze with 96 parts copper	13 to 14 compressions.
With bronze with 95 parts copper	16 to 17 compressions.
Alloy of 95 copper, 4 tin, 1 zinc	14 compressions.
Alloy of 94 copper, 4 tin, 2 zinc	16 to 18 compressions.

From which I conclude that bronze of 96 and 97 parts copper may be employed to great advantage and with no serious inconvenience in the manufacture of medals. Its hardness, much less than that of the alloy of M. de Puymaurin, does not much exceed that of copper; it possesses a certain sonority and casts well, rolls evenly, and its color is more artistic than that of copper.

The action of the press and of heat modifies its density but little.

TABLE 26.

Density.	Medal of 68^{mm}. in bronze, with 4 per cent. tin.	Medal of 68^{mm}. in alloy of Cu 94, Sn 4, Zn 2.
After first annealing	8.926	8.901
After first stroke	8.944	8.909
After second annealing	8.940	8.912
After second stroke	8.941	8.916
After third annealing	8.939	8.910
After third stroke	8.946	8.916
After fourth annealing	8.943	8.911
After fourth stroke	8.947	8.915
After fifth annealing	8.940	8.912

§ VI. PURE COPPER, ITS PERMEABILITY TO LIQUIDS.

Copper alloyed with iron.

Either pure copper which had been used in the preceding experiments or very fine copper in plates, such as is used in the mint at Paris for making medals, was employed.

1. *Tempered and annealed alternately.*

TABLE 27.

	Density.			Density.	
	I. P=101^{gr}.561.	II. P=100^{gr}.892.		III. P=102^{gr}.987.	IV. P=102^{gr}.104.
Copper rolled	8.921	8.923	Copper rolled	8.915	8.919
Copper annealed	8.888	8.891	Copper tempered	8.908	8.911
Copper tempered	8.868	8.856	Copper annealed	8.858	8.865
Copper annealed	8.852	8.853	Copper tempered	8.834	8.840
Copper tempered	8.828	8.831	Copper annealed	8.833	8.840
Copper annealed	8.812	8.809	Copper tempered	8.806	8.819
Copper tempered	8.788	8.785	Copper annealed	8.797	8.810
Copper annealed	8.781	8.783	Copper tempered	8.773	8.785
Diminution of density	0.140	0.140	Diminution	0.142	0.134

2. *Annealed or tempered and rolled alternately.*

TABLE 28.

	Density. I. P.=79^{gr}.835.
Copper rolled	8.877
Copper annealed	8.767 to 8.770
Copper rolled	8.831
Copper annealed	8.751 to 8.756
Copper rolled	8.825
Copper annealed	8.758
Copper rolled	8.868
Copper annealed	8.744 to 8.755

	Density. II. P=79^{gr}.765.
Copper rolled	8.874
Copper tempered	8.786 to 8.791
Copper rolled	8.841
Copper tempered	8.816
Copper rolled	8.850
Copper tempered	8.839
Copper rolled	8.876
Copper tempered	8.849

These experiments show that heat considerably lessens the density of copper, for even after repeated rolling which reduced the thickness of the sheet from 9 millimeters to 1^{mm}.5, the density diminished greatly.

3. *Porosity of copper; its permeability to liquids.*

It will be noticed that in the preceding table, the density after annealing and tempering was represented by several different numbers. The copper gains in weight by remaining even for a little while in water, when it has been heated either in the midst of coal dross, or in the empty box surrounded by coal dross.

Every one who has worked or handled copper has noticed that it almost always contains little cavities, and founders know that it is very difficult to obtain a really sound casting of this metal.

Marchand and Scheerer attribute this to the oxygen contained in the copper, which is disengaged at the moment of solidification by a phenomenon analogous to that which produces the spitting of silver.

Permeability is not due to this cause alone, for rolled copper which is not at all porous, becomes so when reheated in the midst of coal, or in a box surrounded with coal. It depends on various other causes, and especially on the fact that cast copper, even after it has been melted in the presence of carbon, contains a small quantity of oxide which has been produced by the action of the heat at the temperature for annealing.

TABLE 29.

	Weight of a bar of copper.	Immersed for 20 hours in benzine it absorbs from it—
	Gr.	*Gr.*
After the first annealing in a box surrounded with coal	73.693	0.027
After a second annealing in a box surrounded with coal	73.685	0.020
After a third annealing in a box surrounded with coal	73.681	0.012

This increase of weight is due to a simple absorption of the liquid into the metal, for it takes place with very different liquids, and the metal, by simply being exposed to the air, returns to its original weight.

TABLE 30.

	Gr.
Weight of a sample of copper	101.141
Weight of this sample after two days in water	101.168
Weight of this sample after two days in dry air	101.143
Weight of this sample after two days in benzine	101.155
Weight of this sample after two days in dry air	101.142
Weight of this sample after two days in water	101.160
Weight of this sample after two days in dry air	101.145
Weight of this sample after one annealing in coal	101.139
Weight of this sample of copper after two days in water	101.226
Weight of same after two days in dry air	101.144

The copper attained this porosity in rolling.

TABLE 31.

Copper melted, then cast at a low temperature.

	Gr.
Weight in the air	78.442
Weight after one day in water	78.500
Weight after one day in air	78.443
Weight after rolling	78.439
Weight after three days in benzine	78.439

Copper melted, then cast at a very high temperature, does not possess this permeability.

	Gr.
Weight of a sample of copper cast very hot	123.740
Weight of this sample of copper after three days in water	123.738

The density of this sample cast at a high temperature was 8.939, while the density of the sample cast at a low temperature—of the preceding table—was only 8.039. This explains the differences which may be found in the various works upon the density of melted copper. According to Marchand and Scheerer* these densities may vary from 7.720 to 8.921. We have just indicated a superior number to this last, 8.939. The lowest limit given above is never obtained in ordinary circumstances. Generally this density fluctuates between 8.0 and 8.81.

4. This porosity does not exist when the copper is reheated in the air, that is to say, in the ordinary conditions under which this metal is worked in the manufacture of medals.

TABLE 32.

	Density.	
	I. P=$87^{gr}.193$.	II. P=$80^{gr}.077$.
Copper rolled	8.920	8.908
Copper annealed	8.921	8.905
Copper tempered	8.924	8.906
Copper annealed	8.927	8.907
Copper tempered	8.926	8.899
Copper retempered	8.922	8.903
Copper annealed	8.930	8.903

	Density.	
	III. P=$88^{gr}.637$.	IV. P=$79^{gr}.049$.
Copper rolled	8.921	8.919
Copper tempered	8.922	8.921
Copper annealed	8.924	8.923
Copper tempered	8.923	8.921
Copper annealed	8.922	8.922
Copper annealed anew	8.927	8.922
Copper tempered	8.926	8.920

While annealing and tempering considerably lessen the density of copper when not exposed to the air during the operations (Table 27), these same processes do not materially modify the condition of this metal when it is exposed to the air while working it.

Mechanical action and action of heat alternately, on copper heated while exposed to the air.

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* Percy, *Metallurgie*, t. v, p. 67.

TABLE 33.

	Density.	
	I. P=80^{gr}.930.	II. P=81^{gr}.044.
Copper rolled	8.916	8.919
Copper tempered	8.925	8.926
Copper rolled	8.920	8.920
Copper tempered	8.922	8.919
Copper rolled	8.911	8.909
Copper tempered	8.915	8.912
Copper rolled	8.912	8.918
Copper tempered	8.913	8.915
Copper rolled	8.912	8.913
Copper tempered	8.913	8.914
Diminution of density	0.003	0.005

	Density.	
	III. P=80^{gr}.672.	IV. P=81^{gr}.038.
Copper rolled	8.923	8.923
Copper annealed	8.925	8.929
Copper rolled	8.913	8.889
Copper annealed	8.910	8.910
Copper rolled	8.902	8.890
Copper annealed	8.903	8.896
Copper rolled	8.890	8.889
Copper annealed	8.900	8.902
Copper rolled	8.894	8.887
Copper annealed	8.886	8.901
Diminution of density	0.037	0.022

These plates were reduced from a thickness of 9 millimeters to that of 1 millimeter under the same conditions. Comparing these results with those of Table 28, which contains the results obtained when the copper was not exposed to the air while heating, a complete contrast was shown. While annealing and tempering increased the density in the first case, they diminished it in the second.

Another very striking fact when the piece is exposed to the air is, that the increase of density resulting from the heat is very nearly compensated by the tempering, so that the plate, after being made considerably thinner, is found to have the same density as before the operation. By annealing, the uniformity becomes less, and the density materially diminishes. I struck a copper medal at the workshop of the mint, the metal being exposed to the air during the reheating, and the results were as follows:

TABLE 34.

Copper medal in strong relief.

	Density, P = 40^{gr}.430.
Strip rolled	8.909
Strip after the first pass	8.918
Strip after the first tempering	8.918
Strip after the second pass	8.915
Strip after the second tempering	8.916
Strip after the third pass	8.908
Strip after the third tempering	8.912

On the whole, copper exposed to the air during heating, tempered and then struck in the press, shows the same effects as steel annealed and struck. (Table 8.)

The density of both diminishes when they are subjected to mechanical action. Heat restores them sensibly to their original volume, so that we can see how they may be practically employed with advantage in making coins and medals.

The opposite results given by copper exposed to the air during heating and protected from the air (Tables 28 and 33) exhibit the contradictory effects of the experiments of O'Neil and of Marchand and Scheerer,* in which the former obtained a diminution of density by compression, while the others showed a sensible increase.

Copper, in these annealings in the air, oxidizes strongly. In fact, the four samples which were the subject of Table 32 were heated red hot in the midst of coal dust twice in the course of four or five hours.

Their weights, which were—

	gr.		gr.	Oxygen determined.
No. 1,	76.100,	became	75.977	0.123
No. 2,	69.537,	became	69.488	0.049
No. 3,	75.851,	became	75.760	0.091
No. 4,	68.078,	became	68.025	0.053

And this quantity of oxygen is a minimum. The metal after this reduction became again permeable to liquids.

5. The addition to copper of small quantities of foreign matter, iron, for example, increases the porosity, as do small quantities of oxygen. The copper acquires tenacity and elasticity by this adjunction of iron, while retaining a certain malleability.

The question has often been raised as to whether copper allies itself to iron. I give here the results of my experiments on this point.

1st. We heated in a temperature sufficient to melt cast iron—

Copper	90
Cast iron	10

The ingot obtained contained, at its highest part, iron uncombined.

2d. We heated very hot and held some time in fusion—

Copper	90
Rivets	10

The ingot obtained furnished upon analysis—

Top	1,600 iron.
Bottom	365 iron.

3d. We heated very hot and kept melted some time—

Copper	96
Rivets	6

The metal appeared very homogeneous. Its density, taken at two different points, gave—

8.881
8.876

The matter is easily forged, stretches and coils upon itself. It rolls with such facility that *without annealing* a bar of it can be reduced from a thickness of 9 millimeters to that of 1 millimeter. Its tenacity exceeds that of copper.

Examining with a magnifying-glass the plates 1 millimeter in thickness mentioned above, gray spots may be seen at certain points, but analysis of these points shows no material difference between them and other portions. There was found—

Iron	5.383	5.285	5.236

This substance made very hot in the crucible gives a button in which there remains only—

Iron .... 0.167 per cent.

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*Percy, *Metallurgie*, t. v, pp. 69 and 72.

4th. These two metals were alloyed in variable proportions, melted in earthen tubes 15 centimeters in length, and after being kept three hours in fusion, were left to cool slowly.

	Iron, per cent.		
	Top of bar.	Bottom of bar.	Density.
1	12.693	4.545	8.839 to 8.771
2	9.290	3.680	
3	6.876	3.652	
4	4.619	4.520	
5	4.226	4.288	8.885
6	2.950	2.600	

The length of the ingot was from 6 to 8 centimeters. The metal containing 4.5 per cent. of iron appearing homongeneous, some experiments were made upon it comparable to those which were made on copper.

TABLE 35.

	Density. I. $P = 89^{gr}.452$.
Melted metal	8.879
Metal after tempering	8.874
Metal after rolling	8.884
Metal after tempering	8.878
Metal after rolling	8.887
Metal after tempering	8.884
Metal after rolling	8.888
Metal after tempering	8.880

	Density. II. $P = 89^{gr}.481$.
Metal after rolling	8.891
Metal after annealing	8.892
Metal after rolling	8.894
Metal after annealing	8.894
Metal after rolling	8.896
Metal after annealing	8.894

Ferrous copper acts, then, like copper exposed to the air during reheating, or like steel. The action of heat alternating with the rolling restores it evidently to the same volume.

The ferruginous copper is not permeable to liquids. This metal is not, however, a homogeneous alloy, for after being reheated at a very high temperature for three hours and a half, the solidified ingot gave upon analysis—

	Top.	Bottom.
Iron, per cent	6.50	4.00

However, as it had shown a tenacity incomparably greater than that of copper, the following experiments were made with a view to determining the mechanical properties:

TABLE 36.

Elongations in millimeters corresponding to loads in kilograms.

	Name of metals.	P. ct.	Area sq. mm.	800	1,000	1,100	1,200	1,300	1,400	1,500	1,600	1,700
1	Copper of commerce, melted		94	0	1	3	5	(*)				
2	Copper of commerce, rolled		95	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
3	Pure copper, melted		111	1.25	3.0	4.5	5.5	6.0				
4	Pure copper, melted		98	2.5	5.0	(†)						
5	Copper and iron, melted	2	92	0.25	0.25	0.25	0.25	0.75	1.5	2.5	(‡)	
6	Copper and iron, melted	2	92	0.25	0.25	0.25	0.25	0.50	2.0	3.0	3.5	3.5
7	Copper and iron, melted	4.5	97									
8	Copper and iron, melted	4.5	97									
9	Pure copper, rolled		81.5									
10	Pure copper, rolled		89									
11	Copper and iron, rolled	4.5	88									
12	Copper and iron, rolled	4.5	90									

	Name of metals.	P. ct.	Area sq. mm.	1,800	1,900	2,000	2,100	2,200	2,300	2,400	2,500	2,600	2,700	2,800
1	Copper of commerce, melted													
2	Copper of commerce, rolled			0.5	0.5	1.5	2.5	4.5	5.5					
3	Pure copper, melted													
4	Pure copper, melted													
5	Copper and iron, melted	2												
6	Copper and iron, melted	2		4.5	5.5	7.0	8.5	10.0	12.5	15.0				
7	Copper and iron, melted	4.5			0.25	2.5	(§)							
8	Copper and iron, melted	4.5							0.25	1.0	1.20	1.75	2.5	4.0
9	Pure copper, rolled			0.25	0.25	2.0	4.0	8.75	12.0					
10	Pure copper, rolled			0.5	1.5	3.0	4.5	8.0	16.00					
11	Copper and iron, rolled	4.5												
12	Copper and iron, rolled	4.5												

	Name of metals.	P. ct.	Area, sq. mm.	2,900	3,000	3,100	3,200	3,300	3,400	3,500	3,600	Breaking load.	Strength per sq. mm.	Density.
												Kilog.	*Kilog.*	
1	Copper of commerce, melted.													
2	Copper of commerce, rolled.											2,300^{k}	24.210^{k}	
3	Pure copper, melted											1,300	11.711	8.039
4	Pure copper, melted											1,000	10.204	
5	Copper and iron, melted	2												
6	Copper and iron, melted	2										2,400	26.086	
7	Copper and iron, melted	4.5												
8	Copper and iron, melted	4.5										2,800	28.865	8.879
9	Pure copper, rolled											2,300	28.220	8.904
10	Pure copper, rolled											2,300	25.842	
11	Copper and iron, rolled	4.5		0.25	0.5	0.5	1.0	2.5	2.5	4.75		3,500	39.772	8.891
12	Copper and iron, rolled	4.5					0.25	0.75	1.5	3.5	9.0	3,600	40.000	

* The assay was arrested because a blowhole was formed in the sample.

† The broken section presents blowholes.

‡ At 1,600 kilograms one lug of the piece was broken.

§ The sample broke without the two pieces being entirely separated.

(*Ann. de Chim. et de Phys.*, 4 *série*, *t.* xxx, Nov., 1873, 26.)

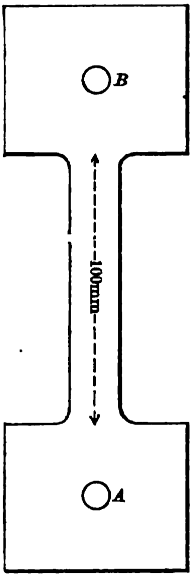
OBSERVATION.—The melted copper (Nos. 1, 3, 4) contains blowholes which destroy its tenacity. It elongates under light loads, and breaks, also, under a small load. The copper acquires a certain tenacity by rolling. While the resistance of melted copper is from 10 to 12 kilograms per square millimeter, that of the same copper attains, by rolling, 25 to 28 kilograms. The ductility is less, and the elongation becomes no longer evident under loads of 1,800 kilograms.

The introduction of iron into the copper leads to great changes in the mechanical properties of the metal:

1st. If the metal has been simply melted, it retains its ductility and elongates under light loads, especially when the quantity of iron exceeds 2 per cent. Its resistance attains to that of copper, which, by rolling, has been reduced to half its thickness.

2d. If the metal has been rolled its ductility is small, but it presents a considerable resistance of 39 to 40 kilograms per square millimeter.

These experiments were made on bars of 2 kilograms weight prepared and cast with care, then cut and worked so as to give them the following form:



In order to determine the resistance, this piece was firmly fastened to the building by an iron fork fitted to A. Another fork placed in B was fixed to a bar forming a lever, at the other end of which was placed a table on which were the weights. The experiments were made at the works of Graffenstaden under the direction of M. Brauer.

This great strength of copper containing iron should not be attributed to the density of the material, for the alloyed copper which presented the greatest resistance had a density of 8.891; that is to say, less than that of pure rolled copper, which was 8.904.

With the exception of the metal bearing the numbers 1 and 2, all these samples were melted with the same copper, rolled to the same point by the same workman, and, in short, treated in precisely the same way.

The hardness of copper melted, rolled, and alloyed with iron presents differences of the same sort. We give here the results which were obtained with the Magna apparatus.

Depth of the impressions produced by the same blow:

	Mm.
Copper melted	2.50
Copper rolled	1.50
Copper alloyed with 3 per cent. of cast iron	1.10
Copper alloyed with 3 per cent. of rolled iron	0.90

Upon the whole, the introduction of trifling quantities of iron into the copper destroys its great softness and porosity, and considerably increases its tenacity and hardness, without destroying its malleability.

M. Bobierre, in order to obtain some idea of the resistance of different metals to corrosion, plunged some into water containing alum, salt, and cream of tartar. I placed in this liquid two plates of equal dimensions, one of pure copper, the other of copper alloyed with 2 per cent. of iron. The copper plate was affected more quickly than the other, and especially was the portion of copper dissolved very strong.

The liquor obtained with ferrous copper is green instead of blue.

At the end of five days, in operating upon two plates of the same size, weighing about 15 grammes, the plate of copper was found to have lost three decigrams more than the plate of ferrous copper.

§ VII.—ALLOYS OF COPPER AND ZINC.

The zinc which I used had been purified by two distillations in the laboratory of the "*Société de la Vieille Montagne*," which generously placed it at my disposal.

I undertook the study of the various physical properties of these bodies, as I did of the alloys of copper and tin, but I was obliged to give up the examination of the fusibility and liquation, because the place where I had specially prepared for this work at the mint was not left at my disposal.

I have nothing special to say on the subject of their hardness; it increases from the alloy 90 of copper to that which contains equal weights of copper and of zinc, Zn Cu.

The alloy $Zn^3 Cu^2$ and the alloy $Zn^2 Cu$ are extremely fragile and break at the first shock of the apparatus described before, and the others, containing more zinc, crack after a few blows.

The density was determined, first, of some ingots weighing from 60 to 100 grammes, then, on account of the greatly differing texture of these alloys, filings of them were operated upon with the greatest possible care. But it is difficult even by a sustained vacuum to eliminate all the bubbles of air, and I was afraid to heat the filings several times in water in order to secure the expulsion of the air, because water is attacked by zinc and the alloys rich in this metal; and, lastly, the volatility of zinc makes it difficult to prepare the alloys in exactly atomic proportions.

I give here, with these reservations, the results obtained:

TABLE 37.

Formula of the alloy.	Centesimal composition.	Actual composition.	Experimental density powder.		Ingots.	Calculated density.		Depth of the impression obtained by the same shock in the Magna apparatus.
				Average.				
$Zn^8 Cu$...	Zn 89.18 Cu 10.82	89.90	7.383–7.248	7.315	7.299	7.351	Material gray, like zinc	1.75^{mm}.
$Zn^4 Cu$.	Zn 80.48 Cu 19.52	79.30	7.920–7.807	7.863	7.215	7.478	Material gray, like fibrous.	Breaks.
$Zn^2 Cu$...	Zn 67.34 Cu 32.66	64.80	8.015–8.075 8.012–8.090	8.048	7.796	7.679	Metal of the tint of antimony, pulverizable.	Do.
$Zn^3 Cu^2$..	Zn 60.73 Cu 39.27	60.35	8.048–7.969 8.378–8.288	8.171	8.039	7.788	Brilliant metal, resembling bismuth; less fragile than the preceding.	Do.
Zn Cu ...	Zn 50.76 Cu 49.23	50.30	8.352–8.261 8.301–8.374	8.304	8.263	7.947	Material with long fibers of a beautiful golden yellow.	1.40^{mm}.
$Zn^2 Cu^3$..	Zn 40.74 Cu 59.26	40.10	8.389–8.268	8.329	8.412	8.110	Less yellow than the preceding.	2
$Zn Cu^2$...	Zn 34.02 Cu 65.98	34.50	8.351–8.430	8.390	8.410	8.345	Brass, ordinary yellow copper.	2.30
$Zn Cu^4$...	Zn 20.49 Cu 79.51	21.80	8.385–8.349	8.367	8.638	8.489	......do................	3.25
$Zn Cu^6$...	Zn 14.66 Cu 85.34	14.90	8.739–8.429	8.584	8.710	8.602	......do	3.50
$Zn Cu^{10}$..	Zn 9.35 Cu 90.65	9.60	8.900–8.767	8.834	8.753	8.707	Substance resembling gold; similar.	2.50
Copper ..	....	......	....		......	....	....	5
Zinc	....	......	......	....	......	....	....	3.25

We see by examining this table that the contraction of the two metals in these alloys is considerable from the second to the sixth; it seems to be at its maximum in the neighborhood of the alloy $Zn^8 Cu^2$, which is also remarkable like the preceding one in that it possesses none of the physical and mechanical properties which are utilized in the metals. They are eminently crystalline and fragile, and appear to be in the series of these alloys what the alloys $Sn Cu^3$ and $Sn Cu^4$ are in the alloys of copper and tin. The theoretical destiny has been calculated with the number of 7.20 that I found to be the average of four concordant determinations on metallic zinc. Afterward the action that tempering, annealing, and rolling exert on the principal brasses utilized in manufacture was determined; *a*, yellow brass containing 65 parts copper and 35 zinc; *b*, metal of 97 parts copper and 9 zinc.

1. ***Alternate tempering and annealing.***

a. Brass.

TABLE 38.

	Density.	
	I. $P = 77^{gr}.071$.	II. $P = 82^{gr}.571$.
After rolling	8.407	8.406
After annealing	8.408	8.413
After tempering	8.412	8.415
After annealing	8.405	8.415
After tempering	8.417	8.418
After annealing	8.410	8.414

	Density.	
	III. $P = 80^{gr}.782$.	IV. $P = 89^{gr}.076$.
After rolling	8.409	8.417
After tempering	8.406	8.411
After annealing	8.401	8.400
After tempering	8.417	8.413
After annealing	8.407	8.411
After tempering	8.431	8.434

b. Similar.

TABLE 39.

	Density.	
	I. $P = 92^{gr}.588$.	II. $P = 94^{gr}.688$.
After rolling	8.812	8.817
After tempering	8.814	8.819
After annealing	8.813	8.814
After tempering	8.812	8.814
After annealing	8.813	8.815
After tempering	8.814	8.814

	Density.	
	III. $P = 94^{gr}.805$.	IV. $P = 92^{gr}.202$.
After rolling	8.818	8.818
After annealing	8.813	8.817
After tempering	8.812	8.816
After annealing	8.810	8.812
After tempering	8.814	8.813
After annealing	8.815	8.813

Thus tempering increases the density of annealed brass, *a*. These two operations do not cause any apparent modifications in the volume of *b*.

2. ***Alternate annealing or tempering and rolling.***

a. Brass.

TABLE 40.

	Density.	
	I. $P = 81^{gr}.366.$	II. $P = 87^{gr}.447.$
After rolling	8.409	8.412
After tempering	8.410	8.411
After rolling	8.414	8.415
After tempering	8.431	8.427
After rolling	8 443	8.436
After tempering	8 433	8.436
After rolling	8.439	8.444
After tempering	8.437	8.437
After rolling	8.439	8.437
After tempering	8.445	8.443

	Density.	
	III. $P = 76^{gr}.412.$	IV. $P = 98^{gr}.172.$
After rolling	8.408	8.411
After annealing	8.411	8.415
After rolling	8.417	8.419
After annealing	8.409	8.417
After rolling	8.424	8.427
After annealing	8.398	8.402
After rolling	8.425	8.432
After annealing	8.414	8.424
After rolling	8.437	8.442
After annealing	8.421	8.430

TABLE 41.

	Density.	
	I. $P = 92^{gr}.848.$	II. $P = 94^{gr}.365.$
After rolling	8.819	8.820
After tempering	8.818	8.820
After rolling	8.813	8.814
After tempering	8.817	8.819
After rolling	8.819	8.818
After tempering	8.817	8.817
After rolling	8.818	8.816
After tempering	8.811	8.812
After rolling	8.822	8.811
After tempering	8.817	8.819

	Density.	
	III. $P = 87^{gr}.566.$	IV. $P = 93^{gr}.566.$
After rolling	8.819	8.819
After annealing	8.817	8.812
After rolling	8.816	8.817
After annealing	8.822	8.816
After rolling	8.818	8.818
After annealing	8.819	8.819
After rolling	8.815	8.818
After annealing	8.813	8.818
After rolling	8.819	8.820
After annealing	8.806	8 808

In these experiments the thickness was reduced from 20 milimeters to 2. It is shown by these numbers that the density of brass is diminished by annealing while it is increased by rolling, and that the density after a long series of operations varies but little. The density is increased still more by tempering. It is said by the experienced that annealing is preferable to tempering in working with brass.

Metal *b* (similar) shows no material variation in its volume after these prolonged operations, and after a considerable thinning. The same thing is true in regard to aluminium bronze, which, like the metal *b*, is capable of being worked to a remarkable degree.

§ VIII.—BRONZES OF ALUMINIUM.

Alloy of copper and nickel.

The bronzes came from P. Mouri & Co.'s.

1*st*. *a. Bronze with* 10 *per cent. of aluminium.*

TABLE 42.

	Density.	
	I. P = $120^{gr}.568$.	II. P = $120^{gr}.275$.
After casting	7. 705	7. 704
After tempering	7. 706	7. 704
After annealing	7. 706	7. 705
After tempering	7. 707	7. 707
After annealing	7. 703	7. 704
After impact	7. 703	7. 702
After tempering	7. 701	7. 702
After impact	7. 699	7. 703

b. Bronze with 5 *per cent. of aluminium.*

TABLE 43.

	Density.	
	I. P = $120^{gr}.575$.	II. P = $129^{gr}.161$.
After casting	8. 252	8. 262
After tempering	8. 259	8. 259
After annealing	8. 255	8. 262
After tempering	8. 257	8. 262
After annealing	8. 257	8. 262
After impact	8. 264	8. 264
After tempering	8. 263	8. 264
After impact	8. 263	8. 265

Tempering, annealing, and mechanical action produce no noticeable variation in the volume of these alloys, of which the working is very regular.

2*d*. *Alloy of copper* 50, *zinc* 30, *nickel* 20, *used in the manufacture of coin for the Honduras.*

TABLE 44.

	Density.	
	I. $P = 99^{gr}.175$.	II. $P = 85^{gr}.730$.
After casting	8. 539	8. 539
After tempering	8. 529	8. 524
After annealing	8. 524	8. 520
After tempering	8. 509	8. 504
After annealing	8. 510	8. 504

	Density. III. $P = 110^{gr}.904$.
After casting	8. 505
After striking	8. 586
After annealing	8. 556
After striking	8. 589
After tempering	8. 577
After striking	8. 589

Density which is increased by mechanical action is diminished by the action of heat.

§ IX.—SOFT IRON.—CAST IRON.—GLASS.

1st. *Soft iron.*—The metal was of good iron having the form of a parallelopiped. It was heated in a porcelain tube in the midst of a current of dry hydrogen. The annealing continued for two or three hours.

TABLE 45.

	Density.	
	I. $P = 75^{gr}.110$.	II. $P = 54^{gr}.990$.
After filing	7. 853	7. 849
After annealing	7. 853	7. 850
After tempering	7. 852	7. 845
After annealing	7. 854	7. 849
After impact	7. 845	7. 849
After annealing	7. 845	7. 845
After impact	7. 842	7. 841
After annealing	7. 841	7. 841
After impact	7. 843	7. 844
After repeated impact	7. 844	7. 847

	Density.	
	III. $P = 75^{gr}.110$.	IV. $P = 54^{gr}.990$.
After filing	7. 853	7. 852
After tempering	7. 846	7. 848
After annealing	7. 853	7. 853
After tempering	7, 850	7. 851
After impact	7. 847	7. 847
After annealing	7. 846	7. 846
After impact	7. 845	7. 844
After annealing	7. 843	7. 844
After impact	7. 847	7. 848
After repeated impact	7. 846	7. 850

2d. *Gray cast iron—its permeability to liquids.*—It was impossible to determine the variations in volume which gray cast iron undergoes when tempered or annealed, because it is permeable to liquids. This porosity is very great, whether the metal be heated in coal dust or exposed to the air during the operation.

a. Cast iron reheated in coal:

TABLE 46.

	Density.			
	I.	II.	III.	IV.
After annealing	7.089	7.098	7.114	7.080
After tempering	7.025	7.040	7.039	7.019
After annealing	6.844	6.914	6.933	6.914

My attention having been called to the great diminution in density, I weighed the samples, and ascertained that their weights increased considerably in water under the ordinary pressure. Thus they weighed—

	Gr.	Gr.	Gr.	Gr.
After the preceding annealing	75.512	75.668	70.191	73.134
And after 20 minutes in water	75.585	75.770	70.265	Not weighed.
Gain in weight	0.073	0.102	0.074	

The following table shows that this increase in weight takes place with non-oxygenized liquids like benzine, and that it is due simply to the absorption of the liquid, for by merely being exposed to the air cast iron regains its original weight.

TABLE 47.

	Gr.	Gain in weight of the liquid.
Weight of a sample of fine gray steel annealed in coal	64.937	
Weight of this sample after 20 hours' immersion in benzine	65.018	
		0.081
Weight of this sample after 24 hours in the air	64.940	
Weight of this sample after a second annealing of 3 hours	64.996	
Weight of this sample after 3 hours' immersion in benzine	65.110	
		0.114
Weight of this sample after 24 hours' in the air	65,001	
Weight of this sample after a third annealing of 3 hours	65.100	
Weight of this sample after 20 hours' immersion in benzine	65.275	
		0.175
Weight of this sample after 24 hours in the air	65.103	

Cast iron, known to be porous, was filed to a thickness of 1 millimeter over the whole surface, then immersed in benzine. The permeability was restored in the inner layers.

A third series of experiments was made in order to determine the effect of annealing and tempering on this porosity, and the results are here given:

TABLE 48.

	Gr.	Gain in weight.
Weight of a sample of tempered cast iron	70.215	
Weight of a sample after a half hour in benzine	70.270	
		0.055
Weight of a sample after 48 hours in the air	70.214	
Weight of a sample after 24 hours in benzine	70.311	
		0.095

	Gr.	Gain in weight.
Weight of a sample after 48 hours in the air	70.216	
It was thoroughly annealed.		
Weight in the air	70.304	
Weight after 18 hours in benzine	70.395	
		0.091
Weight after 48 hours in the air	70.306	
Weight of a sample of annealed cast iron	75.733	
Weight of same after half an hour in benzine	75.820	
		0.087
Weight of same after 48 hours in air	75.735	
Weight of same after 24 hours in benzine	75.875	
		0.140
Weight of same after 48 hours in air	75.735	
It was tempered hard.		
Weight in the air	75.761	
Weight after 18 hours in benzine	75.893	
		0.132
Weight after 48 hours in air	75.758	

b. *Cast iron reheated in a crucible placed in the muffle.*

TABLE 49.

Weight of a sample of fine gray cast iron annealed in the open air	63.652	
Weight of this sample after an immersion of 20 hours in benzine	63.830	
		0.078
Weight of this sample after being exposed to the air for 24 hours	63.755	
Weight of this sample after a second annealing of 3 hours in the muffle	60.362	
Weight of this sample after 20 hours' immersion in benzine	60.493	
		0.131
Weight of this sample after 24 hours' exposure to the air	60.362	
Weight of this sample after a third annealing in the muffle	55.523	
Weight of this sample after 20 hours' immersion in benzine	55.700	
		0.177
Weight of this sample after 24 hours' exposure to the air	55.525	

Steel, soft iron, brass, and bronze under the same conditions do not vary in weight.

3d. *Glass and crystal.*—MM. Chevandrier and Wertheim have shown* that annealing increases the density of glass and crystal. I made some experiments on these materials as limits of compression in order to determine whether the alternate action of tempering and annealing affects this density. I found that tempering materially diminishes this density, while annealing tempered glass increases it, and reciprocally.

TABLE 50.

Crystal of M. Maës.

Samples weighing from 11 to 180 grammes.

	Density.				
After annealing	3.110	3.111	3.110	3.110	3.110
The same not annealed	3.104	3.103	3.104	....	....
The same tempered	3.102	3.103	3.101	3.099	....
These last annealed	3.103	3.109	3.107	3.106	....

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* MM. Chevandrier and Wertheim, *Ann. de Chim. et de Phys.*, 3 série, t. xix, p. 137.

Flint of M. Feil.

Samples weighed 60 to 70 grammes.

	Density.	
After annealing	3.610	3.610
After tempering	3.598	3.598
After tempering	3.602	
After annealing	3.605	

Crown of M. Feil.

	Density.		
After annealing	2.551	2.551	
After tempering	2.544	2.543	
After tempering	2.544	2.544	2.543
After annealing	2.551	Broke.	Broke.

RÉSUMÉ.

1st. The alloys of copper and tin prepared in atomic proportions exhibit a sensible liquation with the exception of those which correspond to the formulæ $\mathrm{Sn\,Cu^3}$ and $\mathrm{Sn\,Cu^4}$. This liquation, slight from the alloy $\mathrm{Sn\,Cu^2}$, increases in the alloys which differ from it in their composition, but it is especially great in the alloys containing a large proportion of tin. By reason of this fact it has been impossible to determine the fusibility of any except the two alloys given above (§ I).

2d. The alloy $\mathrm{Sn\,Cu^3}$ is characterized by special properties. It has a different color from the others; it is pulverizable; it exhibits no sensible liquation, and it is, of all the various alloys of copper and tin, the one in which the contraction is at its maximum. It is, then, the homogeneous alloy of copper and tin, as the alloy $\mathrm{Ag^3\,Cu^4}$ is the homogeneous alloy of copper and silver. In paragraph II is given the density of the principal alloys of copper and tin prepared in atomic proportions. An idea of their hardness is given in the following paragraph.

3d. The bronzes rich in tin (18 to 22 per cent.) increase in density with tempering; and annealing lessens the density of tempered bronze, but in a less proportion. The density is considerably increased by the alternate action of tempering and annealing, and of the press. These effects, the reverse of those in steel, coincide with the fact that tempering softens bronze while it hardens steel (§ IV).

4th. This softening, discovered by D'Arcet, is not sufficient to allow of this bronze being worked cold for industrial purposes. It was shown in paragraph IV that this metal—extremely hard when cold and pulverizable at red heat—is forged and rolled at dark red heat with remarkable facility. This fact enabled me, in common with M. Champion, to succeed in the manufacture of tamtams, and other sonorous instruments, by the method followed in the East.

5th. Tempering produced no apparent softening in the bronzes less rich in tin (12 to 6 per cent.); and if they are tempered for industrial uses it is more especially in order to detach the oxide produced during the reheating of the matter in the course of the operations (§ VI).

6th. It was found that in the axis of a cannon, and especially toward the muzzle, there are some parts very rich in tin and in zinc. Yet the axis is less rich in tin than the periphery. The density does not increase from the muzzle to the breech.

7th. Bronzes of 3 and 4 per cent. of tin possess some great advantages and no important disadvantages, when used in the manufacture of medals.

8th. The density of copper (§ VI), subjected alternately to mechanical action, then to tempering or annealing, displays inverse variations according as it is exposed to the air or sheltered from it during the reheating; while in the first case the mechanical action increases the density, in the second mechanical action diminishes the density.

9th. Some copper, non-porous, becomes sufficiently so by being reheated in coal dust to acquire permeability to liquids (§ VI).

10th. Intense heat, prolonged rolling, and the oxide which forms when the metal is exposed to the air during reheating, render small quantities of iron permeable to liquids.

11th. The introduction of small quantities of iron into the copper gives to it considerable tenacity without destroying its ductility; while rolled copper offers a resistance of 28 kilograms per square millimeter, that of ferrous copper rolled in the same conditions attains to 40 kilograms. The hardness increases equally (§ VI).

12th. The alloys of copper and zinc $Zn^2 Cu^3$, $Zn^2 Cu$, are brittle, like the bronzes $Sn Cu^3$, $Sn Cu^4$; they have none of the physical properties utilized in the metals, and the maximum of contraction takes place near them (§ VII).

13th. Mechanical action increases the density of yellow brass, and this effect is counteracted in part by tempering, and especially by annealing. It is thought that annealing is preferable to tempering in working with brass.

14th. Mechanical action, tempering, and annealing do not sensibly change the volume of similor and of the bronzes of aluminium, alloys remarkable for the facility with which they can be worked (§ VIII).

15th. Gray cast iron heated in coal dust or even in an empty box surrounded with coal, acquires such a porosity that it becomes very permeable to liquids (§ IX).

16th. It becomes equally porous when heated in an empty crucible placed in a muffle, and when the sample is filed in order to remove the oxide which is formed. Copper is not porous in this last condition.

17th. I attempted to determine minutely the modifications which the density undergoes through tempering, annealing, and mechanical action, repeated alternately a certain number of times, and the effects observed were different. While mechanical action increases the density of the bronzes rich in tin, especially (Table 8) of porous copper (Table 28), of copper alloyed with iron (Table 35), of brass, it evidently diminishes the density of copper exposed to the air during reheating (Table 23), and it produces no noticeable alteration in the volume of similor or of aluminium bronze. Tempering produces on brass, and especially on the bronzes rich in tin previously annealed, an increase in density (Tables 5, 6, and 7) contrary to what takes place in steel (Table 11), copper (Tables 27 and 28), and glass (Table 50).

It will be perceived that tempering diminishes the density of a body, because the surface cooled before the center cannot contract freely by reason of the resistance that the interior parts dilated at this moment offer to contraction.

Copper and tin and copper and zinc contract when they unite, and for the rest, the alloys formed experience large liquation. May it not be possible that by slow cooling a part of the copper and of the tin, or of the zinc separates, a phenomenon which should cause a diminution in density, and which cannot take place when the cooling is sudden. I am endeavoring to clear up this point by the study of various slight chemical actions on these alloys and by examining the modfiications which take place in the density of the alloys formed with dilatation of the metals which constitute them.

I may be allowed, in closing, to thank M. Dumas and M. Poussierre for the facilities for working which they procured for me at the mint where these researches were carried on.

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